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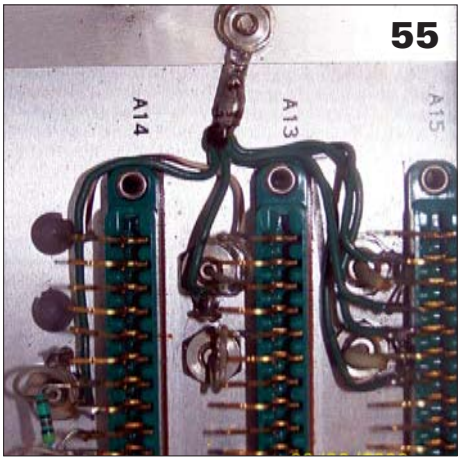

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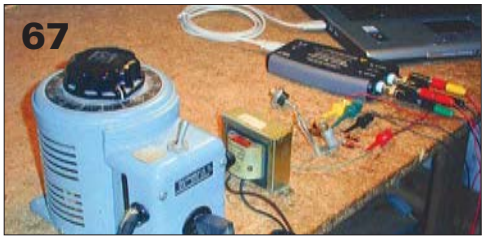

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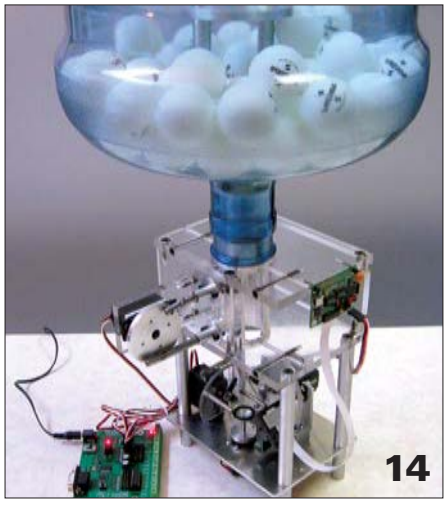

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DEVELOPING PERSPECTIVES

by Bryan Bergeron, Editor

Thanks to several pervasive trends in electronics, including increased miniaturization of components, standardization of signal formats and levels, and economic pressure to minimize design and construction time, there is a movement away from prototyping with components in favor of modules. Instead of working with individual ICs and passive components, cost- and time-conscious engineers design and construct prototypes by working at the system level using function-specific modules. These modules are typically composed of ASICs with a handful of SMT discrete components mounted on a fingernail-sized PC board to facilitate ease of assembly.

This shift toward prototyping with modules means that, for example, instead of considering Ohms law and calculating the value of transistor bias resistors and the like, engineers and electronics enthusiasts are free to focus on function. If you embrace this approach, you'll probably find that you can design, construct, and debug a complete electronic system in a fraction of the time it would have taken you to build a subsystem from discrete components.

Consider, for example, the challenge of designing and constructing a prototype GPS-based navigation system for a mobile robot from discrete components. Even if you're facile with surface mount components, it's likely that the switching power supply will be heavier, require more space, and certainly require more time to construct than the complete navigation system constructed with modules. There is also the issue of cost. Although taking the route of using individual components may seem cheaper at the outset, by the time you consider the PC board, connectors, associated hardware, and the associated shipping charges, the apparent cost advantage of discrete components over function-specific modules often vanishes. Furthermore, if you have limited time to devote to electronics, using modules may be the only practical way to accomplish your goals.

FIGURE 1

My favorite source for miniature, feather-weight modules is SparkFun Electronics (**www.sparkfun.com**). The company offers an amazing assortment of modules — switching power supplies, GPS receivers, Bluetooth modems, cellular transceivers, battery chargers, and a variety of sensors — typically pictured atop a dime or quarter. Modules from SparkFun and similar vendors allow you to focus on functionality and exercise creativity at a higher level. For example, if your goal is to develop a new navigation algorithm for your mobile robot, you probably don't want to waste time debugging the RF front end of a GPS receiver. Instead, for about $70, you can purchase a 12-channel receiver with built-in antenna and interface cable, shown in Figure 1.

Parallax (**www.parallax.com**), maker of the modular BASIC Stamp series, recently increased its footprint in the modular marketplace by offering a BASIC Stamp 2pe motherboard. I've used the self-contained, $80 microcontroller module, which includes two Atmel AVR microcontrollers and a BS2pe BASIC Stamp SX microcontroller, to prototype an RFID reader in less than an hour. Power is supplied by the host computer through the USB port, and interfacing the module to an RFID reader is simply a matter of connecting a reader to an inexpensive plug-in I/O daughterboard on the module, as shown in Figure 2.

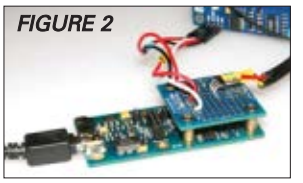

FIGURE 2

The move toward modular prototyping and construction predates the development of microcontrollers and many other digital components. To illustrate the point, I popped the cover of my Magnavox Odyssey video game system console, shown in Figure 3. The unit, produced in 1972, is composed of several 2″ x 2″ analog modules plugged into a motherboard. Although the modules were specific to the Odyssey and used proprietary signals and levels, they were ostensibly easier to replace and repair than a motherboard populated with discrete components. This advantage was never tested, however, as the short-lived Odyssey quickly faded into obscurity with the introduction of the Intel-based digital video games.

The modular approach to construction pioneered by Magnavox and others has applied successfully to products ranging from home TVs and computers to commercial navigation systems. I can remember the distraught look on the faces of fellow technicians when the first module-based Radar systems appeared on the market. As they predicted, Radar repair was quickly transformed from a lucrative, all-day, on-site affair to a 10-minute card swapping exercise that could be performed by anyone with a modicum of diagnostic skill. Defective modules were either discarded or shipped to a central plant where automated jigs were used to quickly diagnose and repair defective components on the modules.

It's important to note that working with modules doesn't obviate the need to understand basic electronics. As Walter Lindenbach points out in his article 'Life of a Wire,' the physics of individual components, including the cables and wires used to connect modules, can profoundly affect circuit operation. Happy prototyping! **NV**

FIGURE 3

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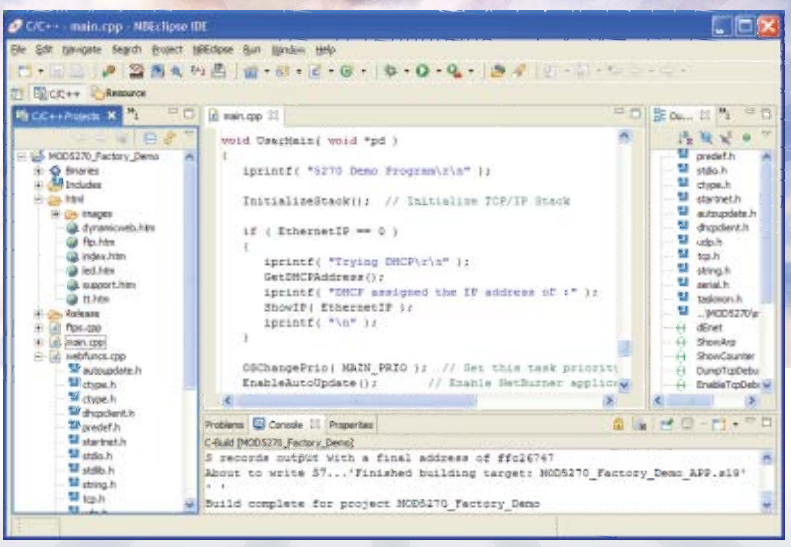

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READER FEEDBACK

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AD(594) DO!

In the November Q&A column, Russell Kincaid designed an eight channel thermocouple interface circuit around the AD594 IC. By coincidence, I helped another hobbyist with a similar problem and also chose the AD594 device.

According to the manufacturer, this device can be used after an analog MUX switch to select multiple thermocouples, yet only use one AD594. Quite a cost savings as the AD594 retails for $10 to $20 each in hobby quantities! The only requirement is that the MUX and related interconnections are held at the same temperature (isothermic) to get good accuracy. The application note AN369 is very helpful (link: **http://tinyurl.com/256lzt**). Keep up the good work!

— Peter J. Stonard
Campbell, CA

Response: Thanks for the feedback! I wish I had found that application note earlier. Anyone planning to measure eight temperatures should read AN369 and install the isothermal block and reference junction per Figure 11 of the AN369. ***— Russ***

VERIFYING BINGO

Admittedly, I've never played Bingo — it looks like fun! I'm having trouble getting my head around the user interface presented in Charles Irwin's project in the Oct. '07 issue.

What is the function of the "verify plus one" and "verify plus 10" buttons? I'm confused why we would add one or 10 to any existing numbers?

As I understand it, the Bingo game has a 'universe' set of integers (1 through 75 inclusive) and as the game progresses, an unused number in the universe set is selected at random and given to the bingo caller. This forms a sub-set of called numbers that can't be called again in this game and are saved for verifying a winner. If a player matches five numbers on their win line, they shout "Bingo!" and halt the game. So we have a third sub-set of four or five 'win' numbers (four if the free cell, if used). The win is declared when these five numbers are verified.

The greatest number of the members in the universe that can be called before a Bingo! is 19 (plus that free space). So the project firmware doesn't need to store all 75 possible universe members — just an array of the sub-set called so far in the current game. Most high-level languages also include a pseudo-random number generator that can be used to select the next picker number.

This is an interesting mental exercise in logic and well suited to a uC project! It seems to me that the firmware should vend random numbers (from the universe set of 75) on each PICKER button request until a player shouts Bingo! Next, the VERIFY button is pressed by the caller, stopping the selection of new numbers, and then automatically scrolling through the members of the called sub-set (plus the free cell) slowly for verification. The caller presses a third button (CONFIRM) as each called number is displayed and verified on the win line of the player's card.

If all five members of the called sub-set are verified, we declare the player the winner (perhaps we have a flashing light and sounder?), and a new game can begin. If the five numbers do not match the called sub-set, we have a denied win. The firmware continues to scroll through the called numbers again (in case one was missed during initial verification) until the picker presses CONTINUE (the fourth button).

After a false win has been disqualified, the same game progresses and new numbers are picked at random from the unused universe set (and copied to the called sub-set) until someone shouts the next Bingo! A new game starts by cycling the power switch, but care must be taken to scramble the pseudo-random number generator (typically by using a new seed number for each game).

— Peter J. Stonard
Campbell, CA

Continued on page 91

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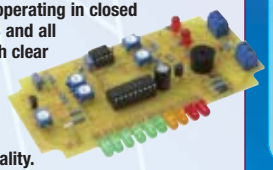
* Car must be fitted with air flow and EGO sensors (standard on all EFI systems) for full functionality.



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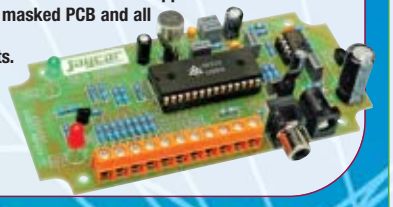

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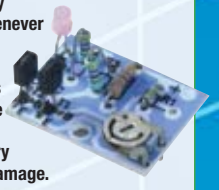

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TECH KNOWLEDGEY 2008

EVENTS, ADVANCES, AND NEWS

■ BY JEFF ECKERT

ADVANCED TECHNOLOGY

NEW CAMERA DETECTS RADIATION THROUGH WALLS

■ Physicist Nick Mascarenhas prepares the neutron scatter camera for a test.

Since 9/11, gamma-ray and neutron detectors have been deployed in many airports and border crossings to help prevent nuclear weapons or radioactive materials from being smuggled into the country. These instruments, however, have some significant limitations in terms of range and shield-penetration capability. A recent development at Sandia National Labs (**www.sandia.gov**), however, promises to detect radiation over much greater distances and through more shielding than is possible with current apparatus.

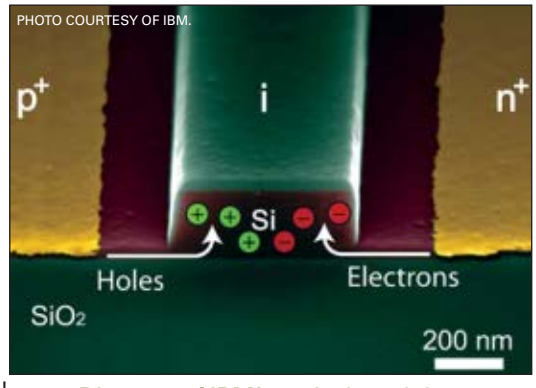
The "neutron scatter camera" is an improvement over traditional neutron detection in that it "sees" only high-energy neutrons and ignores the uninteresting, low-energy ones that are all around us. In a test, it also easily detected and imaged a radiation source from across a hallway and through several walls and cabinets.

Basically, the camera consists of elements that contain proton-rich liquid scintillators in two planes. Neutrons traveling through the scintillators bounce off the protons, energizing them and creating the "scatter." When a proton subsequently loses its energy, it gives off light. Using interactions in the two planes, the camera can ascertain the direction and energy level of the incoming neutrons.

The biggest drawbacks to this approach are size (hand-held detectors are considerably more convenient) and the fact that the scintillator material is flammable and otherwise hazardous to your health. But solid scintillators could eventually eliminate the latter problem.

After further development, the Domestic Nuclear Detection Office plans to ship the camera to Hawaii, where the agency will study its viability for shipboard operation.

IBM CLOSER TO COMPUTING WITH LIGHT



■ Diagram of IBM's optical modulator.

For years, designers have talked about the possibility of computing with light pulses rather than electrical signals. It now looks like scientists at IBM (**www.ibm.com**) have taken a major step toward achieving it. The breakthrough is a device, called a silicon Mach-Zehnder electro-optic modulator, that converts electrical signals into light pulses. This, in itself, is not particularly amazing. However, the IBM version is said to be 100 to 1,000 times smaller than any such devices previously demonstrated, so it could eventually allow complete optical routing networks to be placed on a single chip, eliminating miles of copper wiring.

In operation, the device first converts an electrical signal into a laser beam and applies it to the modulator. It uses tiny "silicon nanophotonic waveguides" to control the light flow on the chip, thus acting like an extremely high-speed shutter. Electrical charges injected into the waveguide change the optical properties of the silicon, thus modulating the beam and creating optical ones and zeros.

According to Dr. T. C. Chen, VP of Science and Technology at IBM Research, "Work is underway within IBM and in the industry to pack many more computing cores on a single chip, but today's on-chip communications technology would overheat and be far too slow to handle that increase in workload.What we have done is a significant step toward building a vastly smaller and more power-efficient way to connect those cores, in a way that nobody has done before."

To put this into perspective, the chip that powers the Sony Playstation 3 has nine cores on one chip. The new technology could allow hundreds or even thousands of cores to be connected in the same space and transfer data among the cores 100 times faster. Using this technology, a supercomputer could someday fit into a standard laptop case.

COMPUTERS AND NETWORKING

COMPUTER FOR THE BOONDOCKS

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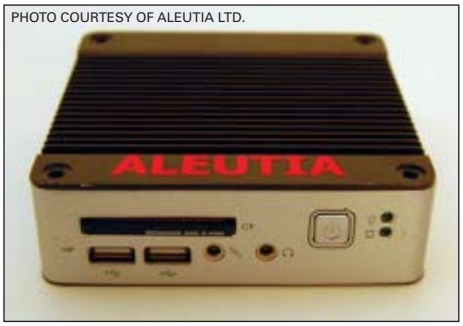


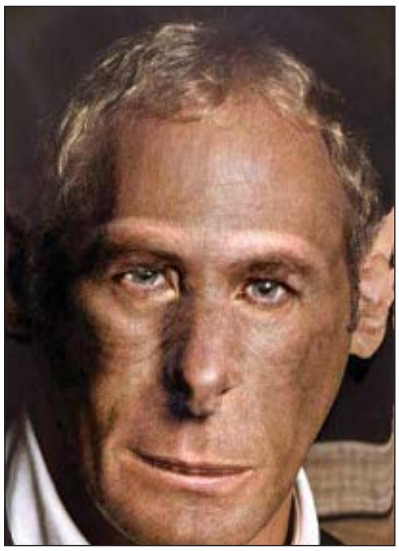
■ The Aleutia E1 can be charged from a solar panel, allowing off-the-grid computing.

Designed for rural Africa and other electrically inhospitable places, the Aleutia E1 draws just 8W of power and runs off a car battery or cheap solar panel. You would expect something less than a computing powerhouse to fit in a box that measures only about 4.5 x 4.5 x 1.4 inches (11.5 x 11.5 x 3.5 cm), and you would be right. The processor is a 200 MHz x86 chip, the machine comes with only 128 MB of SDRAM, and you won't store many videos in the 1 GB compact Flash card. But the E1 and its eight-inch display will run for 3.5 hours on a charge of its internal battery, or you can buy a kit that uses a roof mounted solar panel and external battery to get up to 13 hours of operation.

Other features include three USB ports, one 10/100 Ethernet port, and preloaded Puppy Linux OS 2.14 with a spreadsheet and word processor. The basic package will run you £179 (about $365 unless the dollar keeps falling), £389 ($792) for the "semi-portable" office in a box, or £499 ($1,016) for the complete "ultra-portable" office. Details are available at **www.aleutia.com**.

TRANSFORM YOUR FRIENDS (OR ENEMIES)

The University of St. Andrews, Scotland, Perception Laboratory has provided the world with an amusing digital toy that can be accessed at **http://morph.cs.st-andrews.ac.uk/Transformer/**. All you have to do is upload a .jpg photo of someone you want to mess with, follow a few setup steps, and create a masterpiece of metamorphosis.



■ The devolution of Michael Bolton. Created using the U. of St. Andrews Face Transformer.

You can convert the victim to ages from baby through older adult; choose between several ethnic groups; make him drunk; make a man look feminine or vice-versa; change the image to a painting by Modigliani, Botticelli, Mucha, or El Greco; or see what the person would look like as a Manga cartoon. But best of all, you can also choose the apeman conversion and devolve him back to 50 percent chimp. While you're there, you might also try out the Face Averager and Face Morpher.

MALWARE GROWS BY 100%

The bad news is that the number of new incarnations of malware detected in 2007 by F-Secure Corp. doubled over the previous year, to 500,000. Ominously, this equals the previous 20 years' total manifestations of the malodorous and dangerous stuff. Among the nastiest is the Storm botnet, which is a huge network of Windows PCs that are linked by the Storm worm Trojan horse. It gets into your machine when you are tricked into downloading an email attachment that turns the PC into a "zombie" computer. The machine can then be controlled from afar and used to attack websites, spread infected email, and so on, all without your knowledge. Worse still, the botnet is capable of defending itself against attempts to track down the perpetrators.

Estimates of the Storm botnet's size run as high as 50 million computers worldwide, with up to 6,000 of them dedicated to propagating the worm further. The network, which cumulatively has computing power equal to several supercomputers, is thought to be sending billions of infected messages every day.

The worse news is that the trend is likely to continue as criminals develop increasingly aggressive and refined technologies and focus more attacks on mobile phone and other devices. You can read the full IT Security Threat Summary at **www.f-secure.com/2007/2/**.

CIRCUITS AND DEVICES

SERIAL-TO-ETHERNET GATEWAY

If you need to connect some old RS-232 equipment via TCP/IP protocol, check out the WIZ110SR from Saelig (**www.saelig.com**). It's a plug 'n play gateway module that enables remote checking, management, and control

■ The WIZ110SR Ethernet gateway.
PHOTO COURTESY OF SAELIG CO.

INDUSTRY AND THE PROFESSION

MICROSOFT LEANS ON OLPC

Two years ago, we reported the plans of the One Laptop Per Child organization (**www.laptop.org**) to help out the world's two billion poorly educated children by putting computers into their hands. The cornerstone of the program is the XO computer, which was designed to be as inexpensive as functionally possible. Apparently, the program has begun to catch on, with Uruguay recently ordering 100,000 of them and the "Give One, Get One" program attracting donations from all over the USA and Canada. At present, you can send one to a developing country for $200. The machines run the free, open-source OS Linux, which seems to be a major irritation to the folks at Microsoft; they want a piece of the pie.

In a December press release, the company announced that it will publish "formal design guidelines early next year that will assist Flash-based device manufacturers in designing machines that enable a high-quality Windows experience." The problem is that even a stripped-down, Flash-based Windows XP will likely need 2 GB of memory, and the XO has only 1 GB. Accordingly, Microsoft is now putting the squeeze on OLPC, asking that they redesign the computer with another memory slot. This, of course, would increase the cost of the hardware and dodge the open-source part of the concept.

So far, there is no word as to the charity's reaction, but Microsoft has announced that it will conduct "limited field trials" of XP on the XO this year.

ARE YOU PAID ENOUGH?

If you presently work as an engineer, you can find out how your salary measures up by visiting **www.engineersalary.com**. According to the site, as of 2006, there were 292,800 electrical engineers working in the USA, which is second only to software engineers (329,000). The top 10 percent earned nearly $120,000, whereas the bottom 10 percent pulled in less than $45,000. Job growth into 2009 is projected to be relatively favorable, particularly in defense-related areas, as many engineers will change occupations, be promoted to management, or retire.

of devices via Ethernet and TCP/IP by automatically converting the serial protocol into TCP/IP and vice versa. It comes fitted with both DB-9 and RJ45 connectors, so all you need to do is perform a software setup to create a 10/100 Ethernet interface with a top serial rate of 230 kbps.

The WIZ110SR offers TCP, UDP, IP, ARP, ICMP, IGMP, Ethernet MAC, and PPPoE protocols. Three different modes of operation are supported: TCP server, TCP client, and UDP. (The UDP mode, which doesn't require transmitted data to be acknowledged, can speed up communications.) Operation requires 3.3 V at 150 mA. Best of all, the WIZ will run you only $29.99.

POWER DETECTOR RESPONDS IN 500 NS

■ The LT5570 power detector.
PHOTO COURTESY OF LINEAR TECHNOLOGY CORP.

With the advent of more complex modulation schemes to allow increased data rates in next-generation wireless standards, it is becoming more difficult to measure the resulting high-crest-factor signals. But a solution from Linear Technology (**www.linear.com**) is the LT5570 power detector.

The device provides accurate (±0.5 dB over a range of -40 to +85°C) RMS power measurement of a 40 MHz to 2.7 GHz AC signal over a 60 dB dynamic range, even with a crest factor of up to 12 dB. It also offers a fast response with a full-scale rise time of 500 ns. The LT5570 provides a DC output that is proportional to the RMS value of the input signal power.

Minimum sensitivity is -53 dBm at 880 MHz and -43 dBm at 2.14 GHz. It operates from a single 5V supply, drawing a quiescent current of 26.5 mA. A shutdown feature reduces supply current to 0.1 A. It comes in a 10-lead 3 x 3 mm DFN (dual flat no-lead) package and will run you $5.75 in production quantities. **NV**

RENESAS M16C Platform

M16C - Protecting code investment with true code & pin compatibility

Enables connectivity with CAN, LIN, PLC, ZigBee and DMAC

Renesas Technology

No.1* supplier of microcontrollers in the world

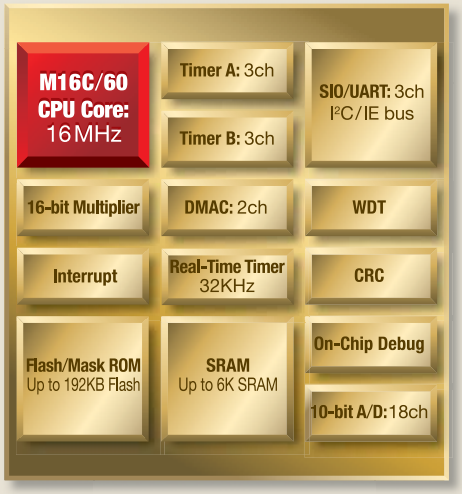
presents the M16C Family, the industry's only fully code compatible platform that addresses the entire 8-bit through 32-bit price/performance application space. The M16C Family of devices protects your code investment with seamless code and pin compatibility across the platform. The M16C platform features optimized peripheral mapping and on-chip memory that permits applications ranging from 24K bytes to 1M bytes, with between 42 and 144 pins, in an efficient 16-bit CISC architecture. Reduce your overall development time and cost with a cross-platform code base and development tools from Renesas Technology.

HOT Products | **M16C/30P Group**

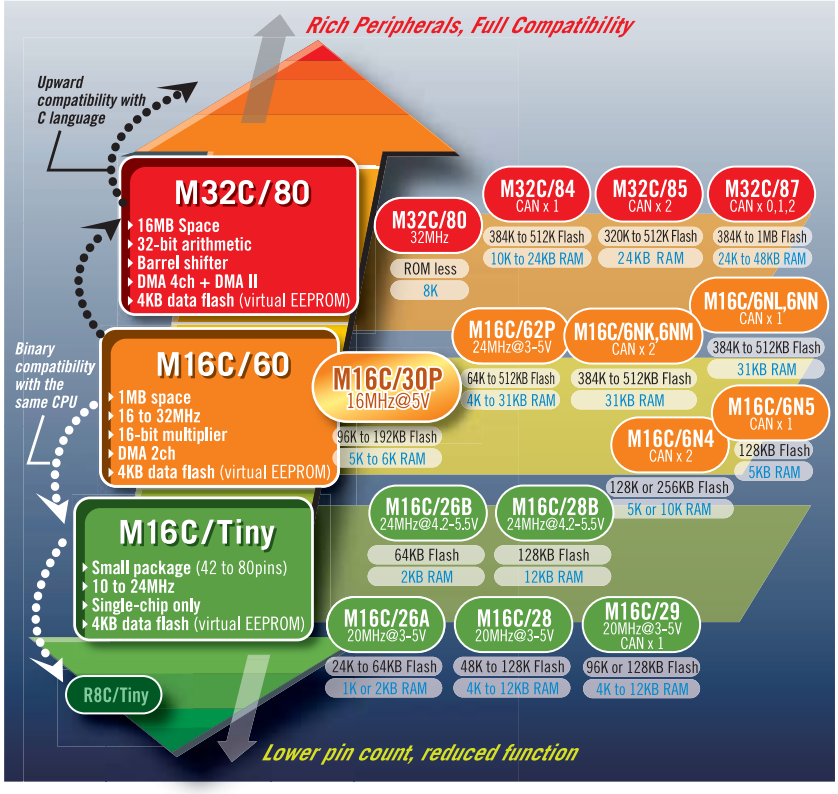
3 cents per pin*

* M30302FCPGP#U5C: 100 pin, LQFP, 128K Flash / 5K RAM

M16C/30P Block Diagram



M16C Product Lineup



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  - Wide selection: 24KB to 1MB Flash, 42 to 144 pin
  - Up/downgrade in same package, same board design
  - Saves costs and protects code investment
- **Powerful and Easy**
  - Banked registers & high speed interrupts (M32C)
  - Optimized instructions for 1cycle operations
  - High-speed hardware multiplier
  - Common Tool Chain across the platform
  - Proven middleware: ZigBee, CAN, motor control
- **Versatile & Efficient**
  - Specialized peripherals: CAN, PLC, motor control
  - Efficient mapping for practical application
  - Flexible DMAC for efficient connectivity
  - Multiple clock sources and power saving modes
- **Quiet EMI/EMS**
  - Built-in noise cancellation, fewer components
- **Reliable and Secured**
  - Trusted flash and protection registers
  - Fail-safe features: oscillator-stop, non-stop WDT

*Source: Gartner (March 2007) "2006 Worldwide Microcontroller Vendor Revenue" GJ07168

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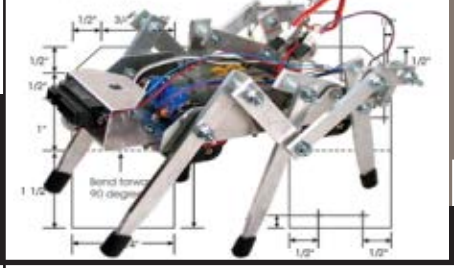


■ BY VERN GRANER

PING PONG PRINTER

IN THE DECEMBER ISSUE, I told you the story of The Ponginator — a 20-foot tall ping pong ball shooting, video screen sporting, light blinking, sound-blasting robot that the Robot Group built for Maker Faire in Austin, TX (Figure 1). The Ponginator was quite a hit, firing eight ping pong balls hundreds of feet out over the crowd every 30 minutes or so. Each ball was custom printed with the logo from The Robot Group and Maker Faire (Figure 2). Though a big success, one thing that sorta snuck up on us was the accumulated cost. Even when ordered in the 500 piece range, the commercially printed ping pong balls cost approximately 60 cents each. At the Maker Faire event, we were loading each of the four pneumatic guns with two balls per barrel on most shots (sometimes more); this resulted in each firing sequence costing almost $5! At this rate (about $10/hour), Ponginator was a bit pricey to operate. Since we had planned to use the Ponginator in other shows in the future, I wanted to find a way to bring the price of operation down. That meant finding cheaper "ammo."

The simplest solution would be to fire plain white ping pong balls. A bit of web searching found a number of suppliers that would ship a gross (144) of these for around $15. This would bring the cost from 60 cents down to just under 10 cents per ball. Although much more economical, the lack of any text or graphic really reduces the "neato factor" that the logo-bearing balls had. I really hoped folks would want to keep these as souvenirs of the event. With nothing special about a boring white ping pong ball, this would be highly unlikely. So the question was, could we somehow print something on the ball ourselves?

■ FIGURE 1. The Ponginator at Maker Faire in Austin.

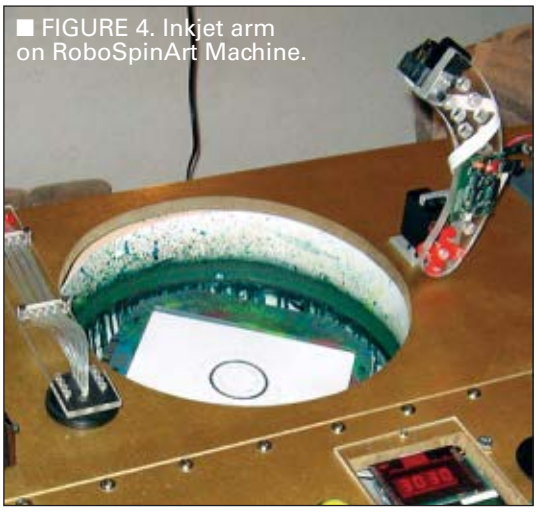
"PONGINATOR NEEDS AMMO BADLY!"

As those of you who read the article on the RoboSpinArt machine know (see *Nuts & Volts*, January '08), I use a serial inkjet printer kit from Parallax (Figure 3) mounted on a retractable servo controlled arm (Figure 4) to inscribe event info on each of the spin art cards just before painting (Figure 5). As I had experience using this kit, I performed a simple test to see if ping pong balls could be used as print media for an inkjet.

First, I hooked up the serial inkjet board and a continuous rotation servo

■ FIGURE 2. Commercially printed ping pong ball.

■ FIGURE 3. Parallax serial inkjet printing kit.



■ FIGURE 4. Inkjet arm on RoboSpinArt Machine.

to an EFX-TEK Prop-2 board (a very convenient BASIC Stamp II based controller). I wrote some code that would dump a single line of text to the serial print interface and then start the servo motor spinning. I placed a blank white ping pong ball on the servo and then held the inkjet cartridge at the "equator" of the ball.

Even with the inkjet cartridge hand-held, the printing came out looking pretty good. And, after drying for just a few seconds, it was both clearly visible and fairly indelible. I could rub the text, and it didn't smear or come off on my fingers.

Now that I had a proof of concept, it was time for some brainstorming on a mechanism with my favorite machinist and fellow roboteer, Rick Abbot.

SODA AND SKETCHES

I lured Rick to a meeting at my house and stuffed him with soda pop and tortilla chips while I sketched out a design for a ping pong ball printer on the white board. He nodded sagely, made some notes and said he might be able to come up with "something" in a bit. He left with a few ping pong balls, a couple of servos, and the serial inkjet kit.

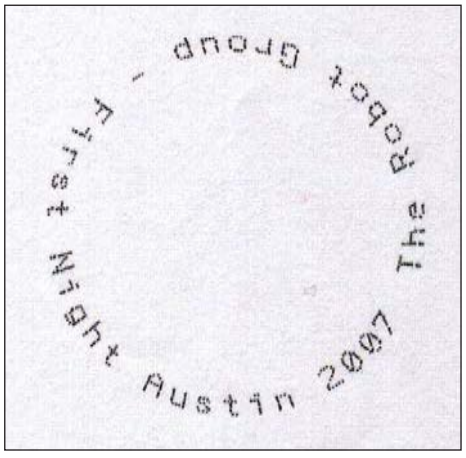
About a week went by, and I got a call from Rick asking if I might be available so he could bring something over. He showed up on my doorstep with the PingPongPrinter Prototype.

Wow! The device was a beautifully rendered Rube Golbergian masterpiece crafted from clear Lucite and aluminum. It was festooned with servos, linkages, push rods, and even an ammo "hopper" made from a five gallon water bottle with a gear motor driven agitator (Figure 6). The agitator had dual vertical rods held together with a dome shaped brace so it could stir up the ping pong ball ammo and make sure there was always a ball ready to drop (Figure 7).

Below the hopper was a loading tube managed by a servo motor controlled "indexer"(Figure 8). The servo was attached to a rotating disk to extend and retract two rods in the path of the ping pong balls. It had two simple, mutually exclusive positions: load and release.

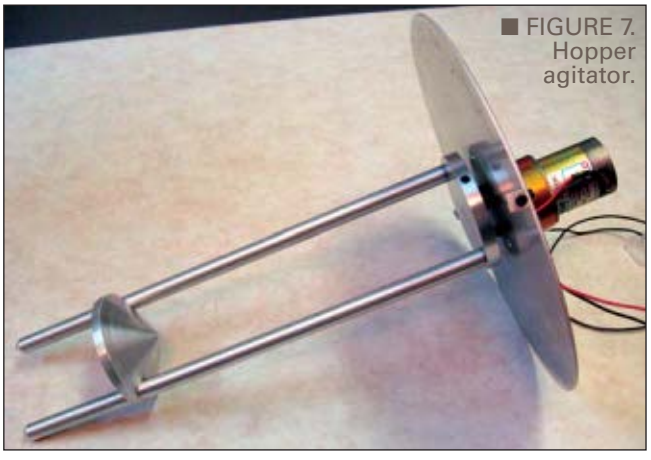
In the load position, the upper rod is retracted, allowing a single ball to fall down into the loading tube that is stopped from falling through by the lower rod. In release position, the upper rod is extended to block the load tube from the rest of the balls in the hopper while the lower rod retracts releasing one ball to fall down to the next stage.

Once a ball falls down the tube, it comes to rest on a small aluminum pedestal that was topped with a rubber o-ring for both traction and

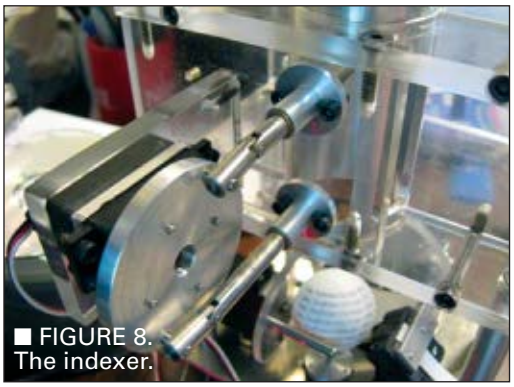


■ FIGURE 5. Inkjet printed text on spinart card.

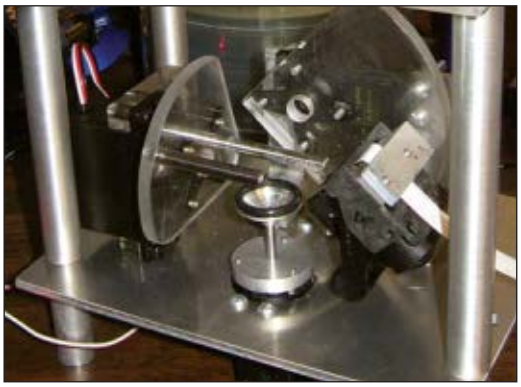
■ FIGURE 6. PingPongPrinter prototype (shown here with agitator removed and placed in the foreground for clarity).



■ FIGURE 7. Hopper agitator.



■ FIGURE 8. The indexer.



■ FIGURE 9. Pedestal, print head, and eject servos.

shock absorption (to keep the ball from bouncing off; see Figure 9). The aluminum pedestal was perched on a continuous motion servo that could rotate the ball under the print head to allow lines of text to be printed. There was also a print head servo that would position the print head around an arc-shaped path. This way, lines of text could be written anywhere between the two "poles" of the ball.

Lastly, a servo motor controlled an eject mechanism that would gently push the printed ball from the pedestal when it was complete. As usual, Rick's amazing mechanical skills had placed a very nice mechanism in my hands (Figure 10). Now, I needed only to write some software to bring it to life.

READY, SET, CODE!

I attached the servos to the Prop-2 board, sat myself down, and stared at the device for a while. Though what it needed to do was relatively straightforward, as I started to make notes on each step in the printing process, it became clear that it was going to be an intricate task to get the printer to perform. I identified each specific function by following the progress of a ball from beginning to end:

1) Move all servos to initial/ready positions.

2) Agitate the ammo in the hopper.

3) Move the indexer from release to load position.

4) Wait for a ball to fall into the loading tube.

5) Move the indexer from load to release position.

6) Wait for the ball to fall and settle on the pedestal.

7) Repeat next steps one time per text message inscribed:
   a) Send text string to the serial inkjet interface card.
   b) Start the pedestal rotation servo.
   c) Wait for one revolution of the pedestal.
   d) Stop the pedestal rotation.
   e) Move the print head to the next line.

8) Retract the print head to read position.

9) Move the eject servo to eject position.

10) Move the eject servo to ready position.

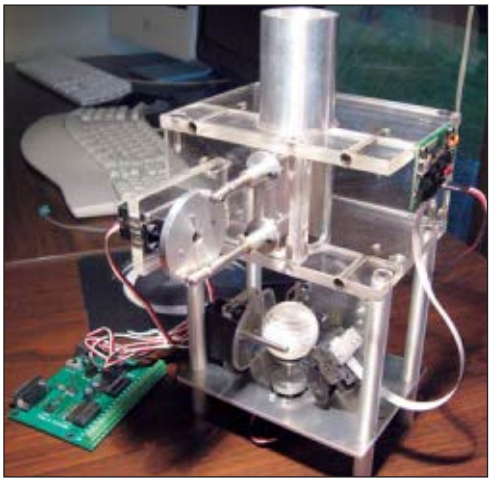
I next took the above functions and started to create subroutines that I could call in sequence. However, at one point it appeared that I would need to do two things at once (rotate the pedestal and send text to the print control board). Since the Prop-2 board is based around the Parallax BASIC Stamp, it's a bit tricky to make things appear to operate in parallel.

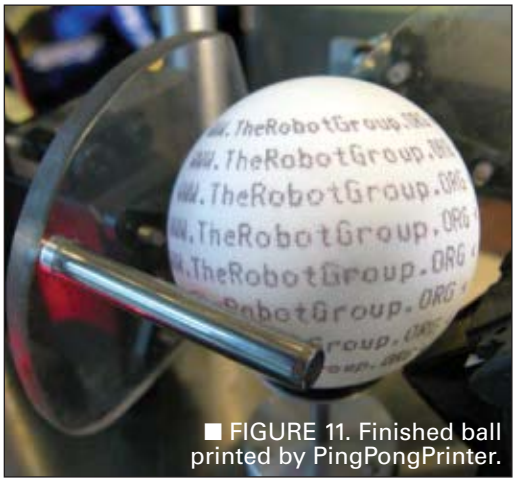
For example, in order for a continuous motion servo to turn, you must feed it a constant "diet" of pulses from the microcontroller. To make sure the pedestal would spin, I created a loop that would send a set of pulses every 20 ms to the servo. But, since the BASIC Stamp was busy sending pulses, it could not also send text strings to the inkjet.

I entertained the idea of some fancy-footwork programming (e.g., making the code jump out of the servo loop on every <x> iterations, fetch a character from the sentence to be printed, send that character to the inkjet, then jump back into the servo loop). However, I always prefer simple solutions during the dev cycle. This is especially important at the beginning of a project where you can waste a lot of time designing tricky code routines that you may later have to abandon if the project moves in another direction.

So, in an attempt at a quick fix, I decided to dump the entire sentence of text to the inkjet interface and then immediately start the loop that rotates the pedestal servo. The

■ FIGURE 10. Close-up of PingPongPrinter mechanism.





■ FIGURE 11. Finished ball printed by PingPongPrinter.

initial test of this method worked pretty well with one small issue. The first two to three letters of text in the sentence were printed on top of each other, making a vertical black line on the ball. The problem was that the inkjet unit would start to print text before the pedestal rotation could begin. There was a simple solution to this problem. I prefaced each text string with three "spaces" so the print head would print nothing before the pedestal could come up to speed. The resulting printed output looked surprisingly good (Figure 11).

Though I'm reasonably sure I could solve the parallel function issues by using a serial servo controller to run the pedestal servo (thereby freeing up the BASIC Stamp to send text), I prefer fewer parts and lower cost if I can manage it. After all, this whole project was motivated by the high cost of the pre-printed ping pong balls. Bottom line is that through trial and error, I've managed to get a working ping pong ball printer using just the servos and a single Prop-2 board. If any more features are added, I may have to switch to a serial servo controller. But, for now, it's nice to know I can print ping pong balls with a single microcontroller solution.

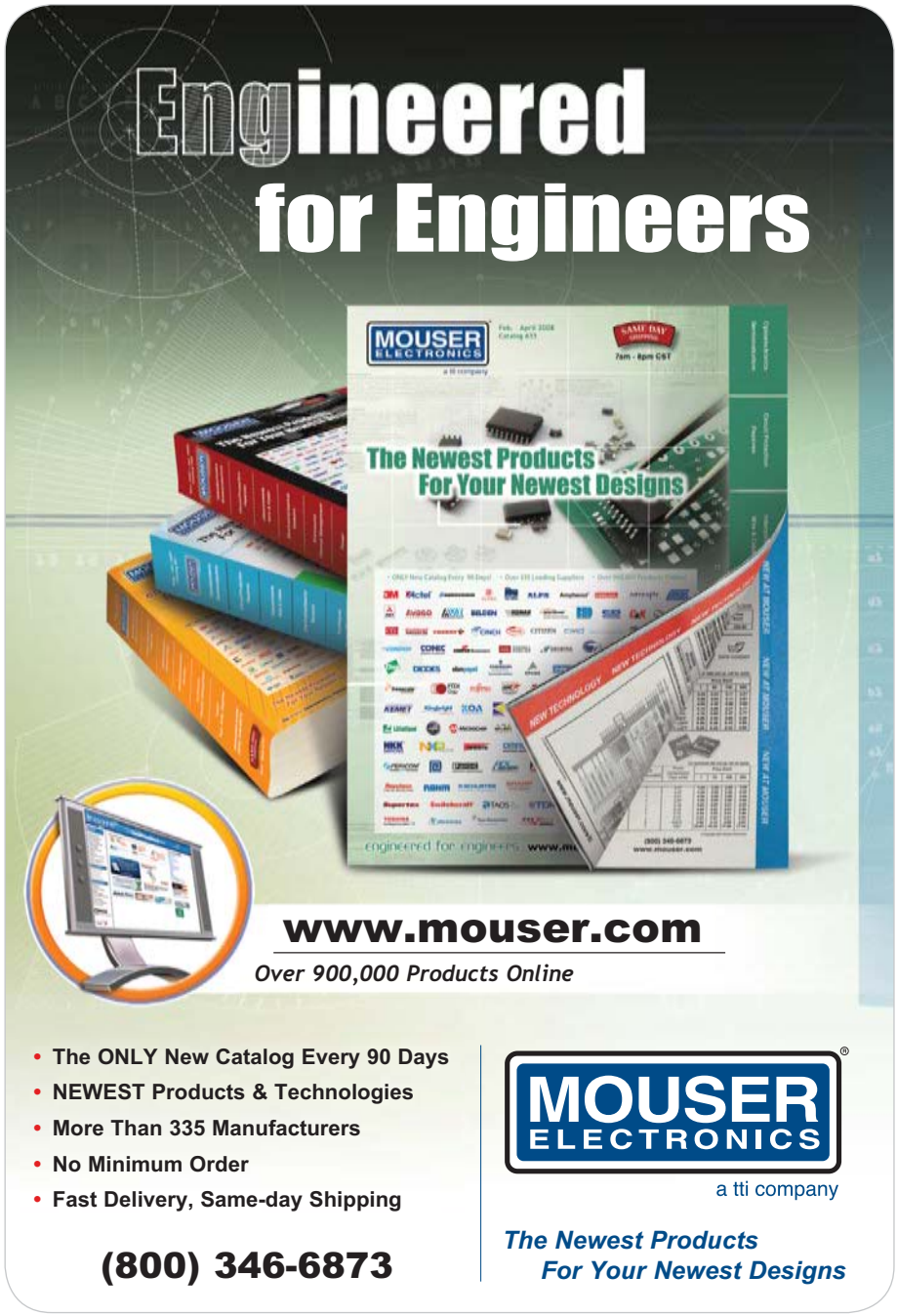
WRAP IT UP, I'LL TAKE IT!

Though the basics of the Ping PongPrinter have been accomplished (Figure 12), I plan to continue to improve it for use at other events. One of the first planned improvements is to place the device in some sort of case to make it more stable and to protect the mechanism from inquisitive fingers. I also envision adding more "bells and whistles" to the device to make its operation even more interesting to watch. The addition of LED lights to the various stages of the device would help observers to follow the progress of the ball as it makes its way from a blank to a fully printed final piece.

Once the entire printer is mounted inside a case, one possible delivery method we've been considering is using the Bernoulli Principle to "float" the finished ball up out of the machine on a cushion of air, leaving the ball suspended on a column of air above a delivery tube when the printing is complete. This would also help to make sure the ink was dry by the time the ball was delivered.

I've also considering adding a coin slot type mechanism to allow the machine to be used for fund raising at events. Some improvements on the inscriptions have also been discussed, such as in addition to the event information, a different fortune printed on each ball. I've also done some experimenting with moving the print head continuously while it is printing, creating a serpentine or candy-stripe text inscription as an additional effect (this effect might be the tipping point that forces me to add that serial servo controller, or maybe even move to a Propeller Chip!).

Anyway you look at it, this should be a fun project to advance. I've included a link in the resources area to a video of the printer in operation so point your browser there if you want to see the PingPongPrinter in action. Once the



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RESOURCES

■ The Robot Group
www.TheRobotGroup.org

■ First Night Austin
www.FirstNightAustin.org

■ EFX-TEK
www.efx-tek.com

■ Parallax Serial Inkjet Kit
http://tinyurl.com/yt8g6h

■ PingPongPrinter Demo Video
www.youtube.com/watch?v=8Ep5OC3E02I

Rick Abbot is a master machinist and serves on the Board of Directors for The Robot Group, Inc.

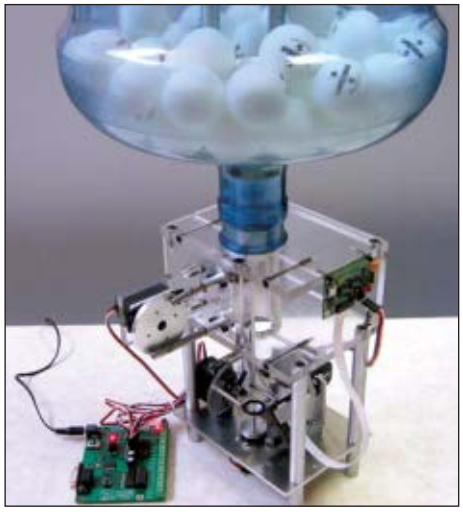
Vern Graner is President of The Robot Group, Inc., in Austin, TX and may be reached via email at vern@txis.com.

I'd like to thank the Austin Word Woman herself, Kate Howard, for her help in crafting this (and other) articles. Thanks Kate!

project has moved further along, I'll try and post some updated videos/pictures to **TheRobotGroup.org** website.

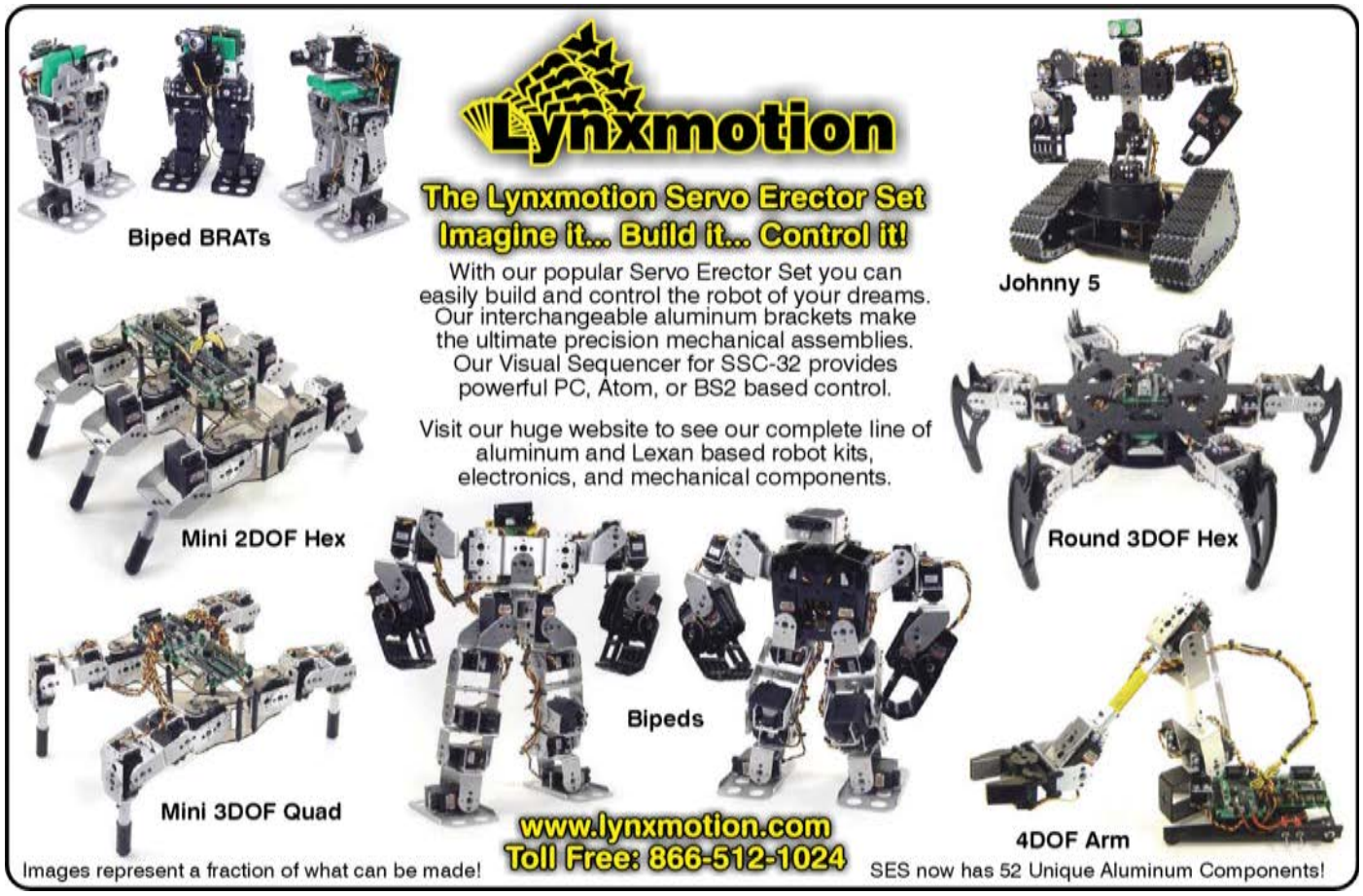
SHOW US YOUR BENCH!

To wrap up my column this month, I'd like to ask a favor of you folks, the readers. Recently, the topic of what I've dubbed the "Habitat For Hobbies" came up among some of The Robot Group members. We started discussing the ideal workbench for crafting and repairing electronics and robotics. I've always been curious about how people get things done in their own workspaces, so, I'd like to ask *Nuts & Volts* readers to take a picture of their workbench and send it to me. Include a description of the tools you think are essential, what you do like and don't like about your current layout, and what you would consider a perfect workspace for projects. Please feel free to offer any advice that would benefit someone just starting out, or that someone ready to remodel their workspace would benefit from knowing.



■ FIGURE 12. PingPongPrinter loaded and ready to print.

I plan to combine the advice and photos for a future article. I'll be taking a picture of my workbench (a.k.a., Disaster Central), so don't be embarrassed to send in a picture of your workbench — warts and all! Please email your submissions to vern@txis.com. Thanks! **NV**



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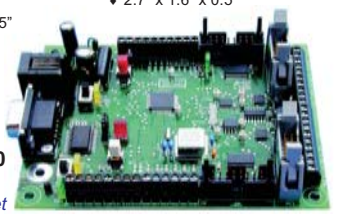
Scorpion XL — $119.99
- Dual **13A** H-bridge *45A Peak!*
- 5V - 24V
- 2.7" x 1.6" x 0.5"

Introducing Dalf

- Closed-loop control of two motors
- Full PID position/velocity loop
- Trapezoidal path generator
- **Giant Servo Mode!**
- PIC18F6722 CPU
- C source for routines provided
- See *www.embeddedelectronics.net*

$250



H-bridges: Use with Dalf or with your Micro/Stamp

$199

OSMC
- Monster power!
- 14-50V **160A!**
- 3.15"x4.5"x1.5"
- 3 wire interface

$79

Simple-H
- 6-28V **25A!**
- 2.25"x2.5"x0.5"
- 3 wire interface
- current & temp protection

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You know it wants one. Go ahead, spoil your robot. Give it the brain and the brawn to take on other robots.

Give your robot the power to do anything it can imagine.

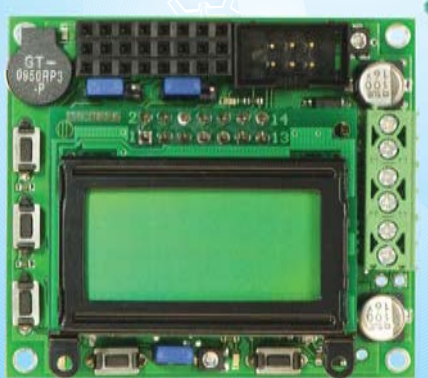
All modules shown actual size

TReX Jr *$59.95*

TReX Jr: all the great features of the full TReX in a lower-power, lower-cost package.

TReX dual motor controller *$99.95*

Orangutan LV-168: full-featured robot controller perfect for low-voltage robots. ATmega168 uC, 2-channel H-bridges, 8x2 LCD, buzzer, and more.



Orangutan LV-168 *$59.95*

TReX dual motor controller: innovative design allows instant switching between radio control (RC) or analog voltage and asynchronous serial (RS-323 or TTL) with a multitude of additional features.

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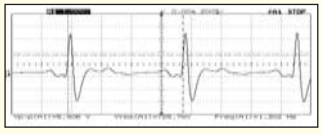
6000 S. Eastern Ave. 12D, Las Vegas, NV 89119

Find out more at **www.pololu.com** or by calling 1-877-7-POLOLU.

Valentine's Day Goodies!

Electrocardiogram ECG Heart Monitor

- ✔ Visible and audible display of your heart rhythm!
- ✔ Bright LED "Beat" indicator for easy viewing!
- ✔ Re-usable hospital grade sensors included!
- ✔ Monitor output for professional scope display
- ✔ Simple and safe 9V battery operation



February is the month for Valentine's Day, and what a great time to think of your heart! Not how many times it's been broken, not how many times it's fallen head over heels in love, but how it actually works...and how it's doing these days!

Use the ECG1C to astound your physician with your knowledge of ECG/EKG systems. Enjoy learning about the inner workings of the heart while, at the same time, covering the stage-by-stage electronic circuit theory used in the kit to monitor it. The three probe wire pick-ups allow for easy application and experimentation without the cumbersome harness normally associated with ECG monitors. The documentation with ECG1C covers everything from the circuit description of the kit to the circuit description of the heart! Multiple "beat" indicators include a bright front panel LED that flashes with the actions of the heart along with an adjustable level audio speaker output that supports both mono and stereo hook-ups. In addition a monitor output is provided to connect to any standard oscilloscope to view the traditional style ECG/EKG waveforms just like you see on ER... or in the ER! See the display above? That's one of our engineers, hooked up to the ECG1C after an engineering meeting!

The fully adjustable gain control on the front panel allows the user to custom tune the differential signal picked up by the probes giving you a perfect reading and display every time! 10 hospital grade re-usable probe patches are included together with the matching custom case set shown. Additional patches are available in 10-packs. Operates on a standard 9VDC battery (not included) for safe and simple operation. Note, while the ECG1C professionally monitors and displays your heart rhythms and functions, it is intended for hobbyist usage only. If you experience any cardiac symptoms, seek proper medical help immediately!

ECG1C	**Electrocardiogram Heart Monitor Kit With Case & Patches**	**$44.95**
ECG1WT	**Electrocardiogram Heart Monitor, Factory Assembled & Tested**	**$89.95**
ECGP10	**Electrocardiogram Re-Usable Probe Patches, 10-Pack**	**$7.95**

Electronic "Love Tester"

- ✔ 10 LED love scale display!
- ✔ Audible love level sound!
- ✔ Great party fun!
- ✔ Heart shaped PC board!

This uniquely shaped "Love Tester" is the ultimate gag for any couple! Designed to check your love life, each partner holds one end of the tester PCB at the appropriate male and female touch pads. Then they romantically join hands and watch the results on the love meter! 10 green, yellow, and red LEDs act like a scale, and just like the carnival when it hits the top they flash, indicating you're a red hot couple! There is also an audible alarm that changes with the "love level". Next time the party isn't going anywhere, bring this out, it's a riot!

Wide sensitivity range is compatible with all couples. Includes a built-in power on/off switch. Runs on a standard 9V battery. Measures 4.1" x 3.1" x .98".

MK149 **Electronic Love Tester Kit** **$16.95**

SMT LED Flashing Heart Pin

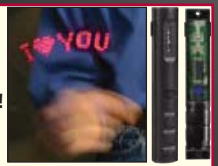
- ✔ Use it as a pin or pennant!
- ✔ 2 brilliant blue LEDs
- ✔ 3 brilliant red LEDs
- ✔ Magnetic pin attachment

This .9" heart-shaped pin is sure to be an attention getter. 5 bright LEDs (2 blue, 3 red) flash brightly, guaranteed to elicit interest from anyone (or anything) attracted to shiny objects! Factory assembled and tested and ready to use.

The unique design can be hung as a pennant using the small hole at the top. But it gets even better, this little heart comes complete with a small but powerful magnet to "pin" it to your clothing...without any holes! Holds it in place and it can even be moved! Runs on two standard CR927 button cells (included) and turns on and off from the back. Show everyone how you feel about that special person in your life with this lively pin!

LFB3 **SMT LED Flashing Heart Pin** **$2.95**

LED Magic Message Wand



- ✔ Message floats in air!
- ✔ Fun at concerts & events!
- ✔ High visibility red LEDs
- ✔ Pre-programmed or custom messages

Use the "Magic Wand" to display your true feelings! Simply shake it back and forth and brilliant messages seem to appear in mid-air! Six high intensity LEDs are microprocessor controlled to display messages and graphics that are pre-programmed into the wand.

You can also custom program a message of your choice! From amazing your friends, making a statement at a concert, or simply telling your loved one how you feel, the message wand can't be beat!

Runs on two AAA batteries (not included), and the auto power off circuit gives you long battery life.

MK155 **LED Magic Wand Kit** **$13.95**

SMT LED Flashing Heart Display

- ✔ Alternating flashing!
- ✔ 6 super bright SMT LEDs!
- ✔ Learn all about SMT!
- ✔ Definitely gets her attention!

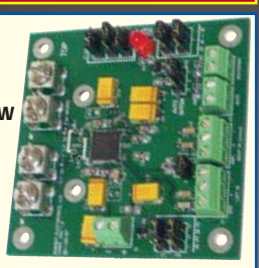
This cute little kit gives you a distinctive red display using 6 Surface Mount (SMT) LEDs. The PC board is in the shape of a red heart. The small size makes it perfect to be used as a badge or hanging pendant around your neck. Even better as an illuminated attention-getting heart to accompany a Valentines Day card!

Makes a great SMT learning kit to bring you into the world of SMT technology, design, and hands-on soldering and troubleshooting. Don't worry, extra SMT parts are included just in case you lose or damage any! Runs on a small CR2025 or CR2032 button cell (not included). Measures 1.9" x 1.7" x .3".

MK144 **SMT LED Flashing Heart Kit** **$11.95**

The Latest... And the Greatest!

Subminiature 40W Stereo Amplifier



- ✔ 2 independent 20W amplifiers in one SMT package!
- ✔ Super efficient Class D spread spectrum design!
- ✔ Built-in click and pop suppression!
- ✔ Selectable gain from +22dB to +36dB!
- ✔ Logic level mute and shutdown!
- ✔ Runs cool, no heat sink required!
- ✔ Built-in thermal protection!
- ✔ Runs on 10 to 18 VDC

New For 2008

The UAM4 is the big brother to the extremely popular UAM2. It uses the latest spread spectrum amplifier technology to bring you clear, crisp, high-power audio without any of the heat which is normally associated with such an amplifier. It's extremely clean Class D design produces two independent 20 watt outputs! This can also be bridged to an extremely efficient (87%!) single channel (mono) 40 watt amplifier.

And at 40 watts, you're probably already wondering about the heatsink requirements to dissapate the heat, right? Stop wondering, there's no heat, so there is no heatsink required! And all that power is generated in a single SMT device the size of your thumbnail on a small 2½" square board!

The high impedance input is designed to use your choice of either a balanced line input or an unbalanced signal source using easy to connect Euro terminal blocks. Logic connections to ground are also provided to mute and/or shut down the amplifier. You can also enable the built-in over temperature signal to activate one of these controls automatically! Easy to use board jumpers offer selectable gain of +22dB, +25dB, +29.5dB or +36dB to match your input levels. Board jumpers also enable protection and shutdown options as well as stereo/mono/bridge mode. The amplifier also features built-in click and pop suppression to protect not only your ears and sanity, but your speakers and equipment!

Power input for maximum rated output is 18VDC at 2.64A. Input voltage can be reduced to a minimum of 10VDC while maintaining the same high efficiency operation with reduced output power. If you're looking for an incredible stand-alone stereo (or mono) amplifier to build into your equipment, vehicle, speakers, or application, the UAM4 is the latest and the greatest!

UAM4 **Subminiature 40W Amp Kit** **$69.95**

Retro Nixie Tube Clocks

New For 2008

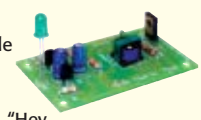
- ✔ .7" bright orange Nixie display!
- ✔ 12/24 hour soft-fade display!
- ✔ Today's technology with yesterday's display!
- ✔ Custom hand-made wooden base!
- ✔ The ultimate conversation piece!

The Nixie tube made it's debut in 1954 and became the standard in high-end test and military equipment. We brought it back in 2008 in one of the neatest digital clocks available today!

It features six IN14 Nixie tubes mounted in a beautiful hand crafted and hand rubbed Teak and Maple base. Advanced features include 12/24 hour format, brightness control, soft fade out, and auto-dim for selected windows of time. Runs on 12VDC with included AC power supply and utilizes a crystal time base accurate to 20ppm. You will be mesmerized watching the bright orange glow! Available in kit form or factory assembled

IN14TM	**Retro Nixie Clock Kit**	**$329.95**
IN14TMWT	**Retro Nixie Clock Asmb**	**$369.95**

Tickle-Stick Shocker



The kit has a pulsing 80 volt tickle output and a mischievous blinking LED. And who can resist a blinking light and an unlabeled switch! Great fun for your desk, "Hey, I told you not to touch!" Runs on 3-6 VDC.

TS4 **Tickle Stick Kit** **$12.95**

Super Snoop Amplifier

Super sensitive amplifier that will pick up a pin drop at 15 feet! Full 2 watt output drives any speaker for a great sound. Makes a great "big ear" microphone to listen to the "wildlife" both in the field and in the city! Runs on 6-15 VDC.

BN9 **Super Snoop Amp Kit** **$9.95**

Passive Aircraft Monitor

The hit of the decade! Our patented receiver hears the entire aircraft band without any tuning! Passive design has no LO, therefore can be used on board aircraft! Perfect for airshows, hears the active traffic as it happens! Available kit or factory assembled.

ABM1 **Passive Aircraft Rcvr Kit** **$89.95**

LED Blinky

Our #1 Mini-Kit for 35 years! Alternately flashes two jumbo red LED's. Great for signs, name badges, model railroading, and more. Used throughout the world as the first learning kit for students young and old! Great solder practice kit. Runs on 3-15 VDC.

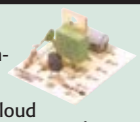
BL1 **LED Blinky Kit** **$7.95**

Laser Light Show

Just like the big concerts, you can impress your friends with your own laser light show! Audio input modulates the laser display to your favorite music! Adjustable pattern & speed. Runs on 6-12VDC.

LLS1 **Laser Light Show Kit** **$44.95**

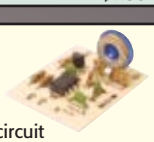
Electronic Siren



Exactly duplicates the upward and downward wail of a police siren. Switch closure produces upward wail, releasing it makes it return downward. Produces a loud 5W output, and will drive any speaker! Horn speakers sound the best! Runs on 6-12 VDC.

SM3 **Electronic Siren Kit** **$7.95**

Universal Timer



Build a time delay, keep something on for a preset time, provide clock pulses or provide an audio tone, all using the versatile 555 timer chip! Comes with circuit theory and a lots of application ideas and schematics to help you learn the 555 timer. Runs on 5-15 VDC.

UT5 **Universal Timer Kit** **$9.95**

Voice Activated Switch

Voice activated (VOX) provides a switched output when it hears a sound. Great for a hands free PTT switch or to turn on a recorder or light! Directly switches relays or low voltage loads up to 100mA. Runs on 6-12 VDC.

VS1 **Voice Switch Kit** **$9.95**

Tone Encoder/Decoder

Encodes OR decodes any tone 40 Hz to 5KHz! Add a small cap and it will go as low as 10 Hz! Tunable with a precision 20 turn pot. Great for sub-audible "CTS" tone squelch encoders or decoders. Drives any low voltage load up to 100mA. Runs on 5-12 VDC.

TD1 **Encoder/Decoder Kit** **$9.95**

RF Preamplifier

The famous RF preamp that's been written up in the radio & electronics magazines! This super broadband preamp covers 100 KHz to 1000 MHz! Unconditionally stable gain is greater than 16dB while noise is less than 4dB! 50-75 ohm input. Runs on 12-15 VDC.

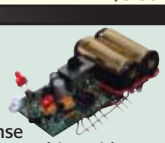
SA7 **RF Preamp Kit** **$19.95**

Touch Switch

Touch on, touch off, or momentary touch hold, it's your choice with this little kit! Uses CMOS technology. Actually includes TWO totally separate touch circuits on the board! Dries any low voltage load up to 100mA. Runs on 6-12 VDC.

TS1 **Touch Switch Kit** **$9.95**

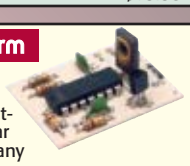
Walking Electronic Bug



Built around a pair of subminiature cell phone motors, this bug wanders around looking for things to bump into! Sensors below his LED eyes sense proximity and make him turn away! Steer him with flashlights too! Runs on two "N" batteries.

WEB1 **Walking Bug Kit** **$29.95**

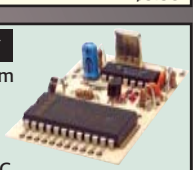
Mad Blaster Warble Alarm



If you need to simply get attention, the "Mad Blaster" is the answer, producing a LOUD ear shattering raucous racket! Super for car and home alarms as well. Drives any speaker. Runs on 9-12VDC.

MB1 **Mad Blaster Warble Alarm Kit** **$9.95**

DTMF Encoder Decoder



Decodes standard Touch Tones from telephones, radio, or any audio source. Detects and decodes any single digit and provides a closure to ground up to 20mA. Great for remote tone control Runs on 5VDC.

TT7 **DTMF Encode/Decode Kit** **$24.95**

Practice Guitar Amp & DI

Practice your guitar without driving your family or neighbors nuts! Works with any electric, acoustic-electric, or bass guitar. Plug your MP3 player into the aux input and practice to your favorite music! Drives standard headphones and also works as a DI for any home stereo!

PGA1 **Personal Practice Guitar Amp Kit** **$64.95**

Water Sensor Alarm

This little $8 kit can really "bail you out"! Simply mount the alarm where you want to detect water level problems (sump pump!). When the water touches the contacts the alarm goes off! Sensor can even be remotely located. Runs on a standard 9V battery.

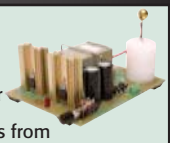
MK108 **Water Sensor Alarm Kit** **$7.95**

RF Actuated Relay

Just what you need when adding a preamp or power amp in line with an antenna! Auto senses RF and closes an on-board DPDT relay that's good to UHF at 100W! Also great to protect expensive RF test equipment. Senses as low as 50mW! Runs on 10-15VDC.

RFS1 **RF Actuated Relay Kit** **$19.95**

HV Plasma Generator



Generate 2" sparks to a handheld screwdriver! Light fluorescent tubes without wires! This plasma generator creates up to 25kV at 20kHz from a solid state circuit! Build plasma bulbs from regular bulbs and more! Runs on 16VAC or 5-24VDC.

PG13 **HV Plasma Generator Kit** **$64.95**

Air Blasting Ion Generator

Generates negative ions along with a heafty blast of fresh air, all without any noise! The steady state DC voltage generates 7.5kV DC negative at 400uA, and that's LOTS of ions! Includes 7 wind tubes for max air! Runs on 12-15VDC.

IG7 **Ion Generator Kit** **$64.95**

Davis OBDII *CarChip Pro*

The incredible OBDII plug-in monitor that has everyone talking! Once plugged into your vehicle it monitors up to 300 hours of trip data, from speed, braking, acceleration, RPM and a whole lot more. Reads and resets your check engine light, and more!

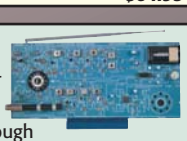
8226 **CarChip Pro OBDII Monitor** **$99.95**

Stereo Ear Super Amplifier

Ultra high gain amp boosts audio 50 times and it does it in stereo with its dual directional stereo microphones! Just plug in your standard earphone or headset and point towards the source. Great stereo separation besides! Runs on 3 AAA batteries.

MK136 **Stereo Ear Amplifier Kit** **$9.95**

IC AM/FM Radio Lab



Learn all about AM/FM radio theory, IC theory, and end up with a high quality radio! Extensive step-by-step instructions guide you through theory, parts descriptions, and the how's and why's of IC design. Runs on a standard 9V battery.

AMFM108K **AM/FM IC Radio Lab Kit** **$34.95**

SMT Multi-Color Blinky

The ultimate blinky kit! The 8-pin microcontroller drives a very special RGB LED in 16 million color combinations! Uses PWM methods to generate any color with the micro, with switchable speed selection. SMT construction with extra parts when you lose them! Runs on 9V battery.

SBRGB1 **SMT Multi-Color Blinky Kit** **$29.95**

3-In-1 Multifunction Lab

The handiest item for your bench! Includes a RoHS compliant temp controlled soldering station, digital multimeter, and a regulated lab power supply! All in one small unit for your bench! It can't be beat!

LAB1U **3-In1 Multifunction Solder Lab** **$129.95**

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Q&A

WHAT'S UP:

Join us as we delve into the basics of electronics as applied to every day problems, like:

- ✓ Digital Compass
- ✓ Motion Detectors
- ✓ Improved TV Reception

■ WITH RUSSELL KINCAID

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist. Feel free to participate with your questions, comments, or suggestions.

Send all questions and comments to:
Q&A@nutsvolts.com

DIFFERENTIAL PROBE

Q I would like to make a differential probe to use with my oscilloscope. I did some investigating on the Internet and I found while you could make up a circuit with discrete components, the components would have to meet very tight tolerances and be perfectly matched. Are there readily-available integrated circuits made that could be used and can you suggest a circuit? I am not sure about voltage ranges, but I would like something that could be used over a range of voltages from very small to 700 volts, and handle AC or DC.

— Richard A. Phillips

A Most dual trace scopes have a switch for adding the A and B channels to give a differential display. If you have a single channel scope, it is possible to isolate the scope from ground and connect the probe ground to one side of the circuit and the probe to the other side. If you are working with AC power circuits, this is dangerous and an OSHA no-no.

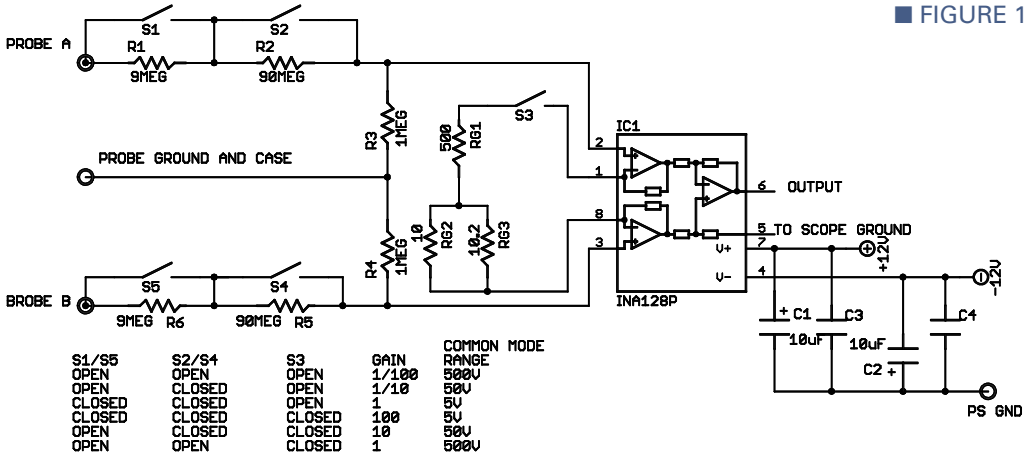
If you are using a single channel scope, the safe way to do differential display is to use an instrumentation op-amp. The circuit in Figure 1 uses a INA128 instrumentation amp from Texas Instruments (formally from Burr-Brown). The gain is set by Rg to be 100 (40 dB) because the worst case input common mode range is ±5 volts. With 100:1 input attenuation, the input common mode can be ±500 volts and still have AC gain of one. If you keep the output signal below ±5 volts, the input common mode can exceed 1,000 volts. The gain error is ±.05% plus the resistor tolerance.

If you have small common mode voltage and want to measure 700 VAC, then the gain resistor, Rg, must be opened because the output voltage cannot exceed ±10 volts. With Rg open, the gain is one so 700 volts input will give seven volts output when both S1 and S2 are open.

If you have a 10X/1X probe, the switches, S1 and R1, are in the probe; otherwise, you need to use a 1X probe and put R1 and S1 in the box. The power supply ground (PS GND) can be common with the probe ground or not.

Keeping the grounds separate may avoid ground loop problems. Nine meg and 90 meg resistors are not generally available; you will have to put in series a number of 1% resistors and (optionally) a pot for final adjustment. The 22 meg resistors are 5%, so it is possible that four of them will exceed 90 meg by two meg, so I advise buying 10 or more and select four that total less than 90 meg.

■ FIGURE 1



IMPROVED TELEVISION RECEPTION

Q Where I currently reside, I don't have very good reception for my television. I have heard that I could use a wide band RF amplifier to get better reception. Unfortunately, I have not been able to find any schematics for a wide band RF amp. I would

appreciate a schematic if at all possible.

— Nathanial C. Blacker

A If you have a roof mounted community antenna, then the reception is probably as good as you can get. If you are using a rabbit ears type of antenna, then you need a better antenna. In order for an RF amp to do any good, it must have a lower noise figure than the TV RF amp.

For a better antenna, consider the Terk TV55. It is a helical antenna with an amp and covers VHF/UHF. I don't have any experience with it, but reviews are good. The cost is about $100 and you can order from: Crutchfield, P.O. Box 9032, Charlottesville, VA 22906-9032. The antenna is less than four feet long and about three inches in diameter, so it should fit in your space.

The RF amp schematic that you requested is shown in Figure 2. It is not real wide band — it only covers the VHF band — but the gain is nearly 20 dB (see Figure 3). The transistor, 2SC3356/NE85633, is an SOT-23 surface mount and the resistors should be surface mount as well for best performance. The input impedance of the amplifier is probably not 75 ohms, so the cable from the antenna to the amp should be short to avoid reflection problems.

HD RADIO

Q The question I have is about the HD radio broadcasts. Is there a way to modify a regular FM radio to receive these HD stations?

— Bryan Fischer

A The short answer is no. Broadcast stations now have the ability to send all analog, hybrid digital (including analog), extended hybrid digital with analog, or all digital (no analog). There are presently no receivers available for all digital FM and no all digital stations, as far as I know. The digital signal can be subdivided into multiple channels, each carrying a different signal. The digital signal is lower power than the analog and if the digital signal is too weak, the receiver is designed to switch to the analog signal.

The extended hybrid digital spectrum is wider than the old analog signal so there would be some degradation if the unmodified RF sections of the radio were used. The detector would have to be redesigned and all the processing after the detector would have to be designed.

Presently, reception of HD radio is free but it is possible that in the future, you will be able to purchase specific channels (rock and roll, oldies, classical, etc.). European countries have adopted a different standard, so your USA radio won't work over there and vice versa.

PARTS LIST

PART	DESCRIPTION	MOUSER PART NUMBER
• S1-S5	SPDT Mini Toggle	108-1AS1T1171-EVX
• R1, R5	4 x 2.21 MEG +160K	71-CCF55-2.21M, 71-CCF55-162K
• R2, R4	4 x 22 MEG + 2 MEG POT	291-22M-RC, 81-PV37W205C01B00
• RG1	500 OHM, 0.1%	71-PTF56500R00BYBF
• RG2	10 OHM, 1%	271-10-RC
• RG3	10.2 OHM, 1%	271-10.2-RC
• IC1	INA128P	595-INA128P
• C1, C2	10 µF, 16V, 10%	581-TAP106K016SRW
• C3, C4	0.1 µF, 50V, X7R	80-C320C104K5R

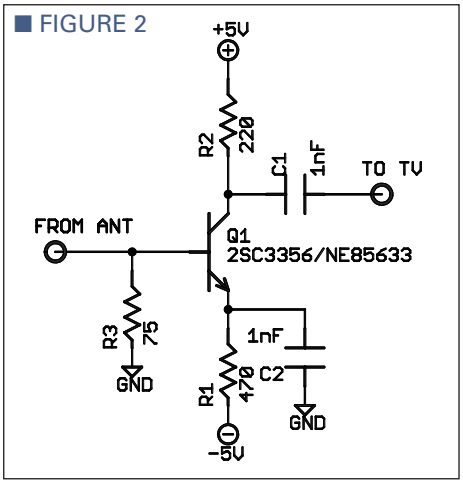
CONVERT SEQUENTIAL PULSES TO FOUR OUTPUTS

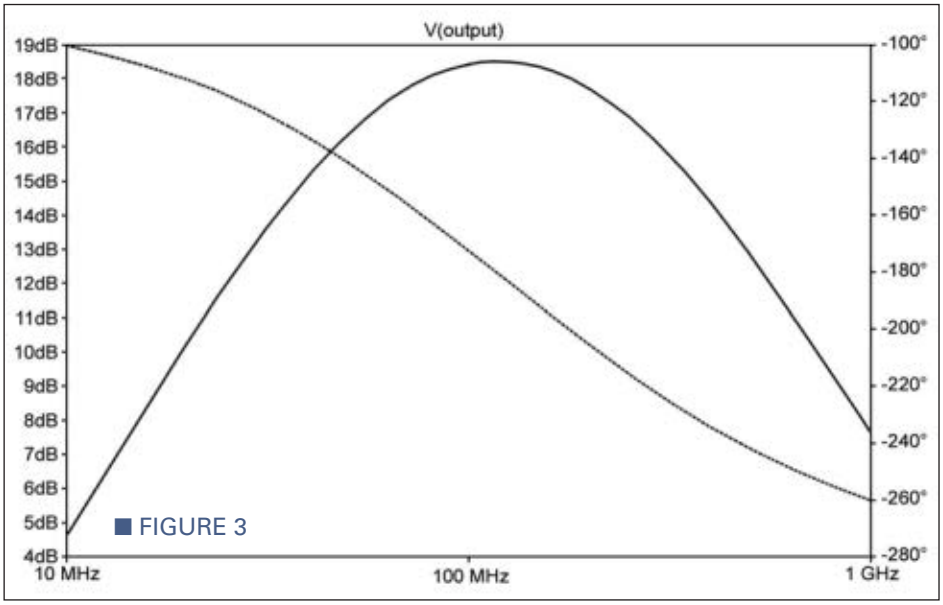
Q I have a stand-alone wireless motion detection unit that reports alerts from four detectors. The system sounds one to four beeps to distinguish between the detectors, and also conveniently closes a relay in sync with the beeps. I would prefer the output to light one of four LEDs, or perhaps trigger a variety of voice alerts. How would I construct a circuit to convert a sequential series of pulses to switch four separate outputs?

— Rob Gordon

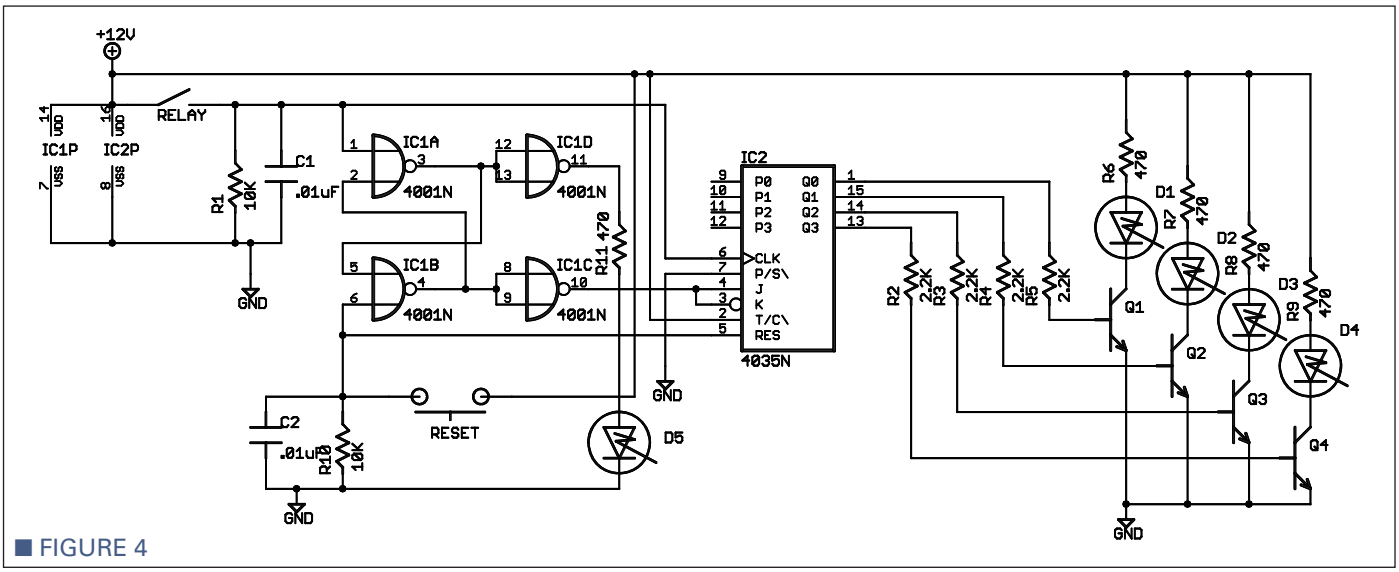
A A shift register seems the logical device for this application. The relay becomes the clock; the

■ FIGURE 2





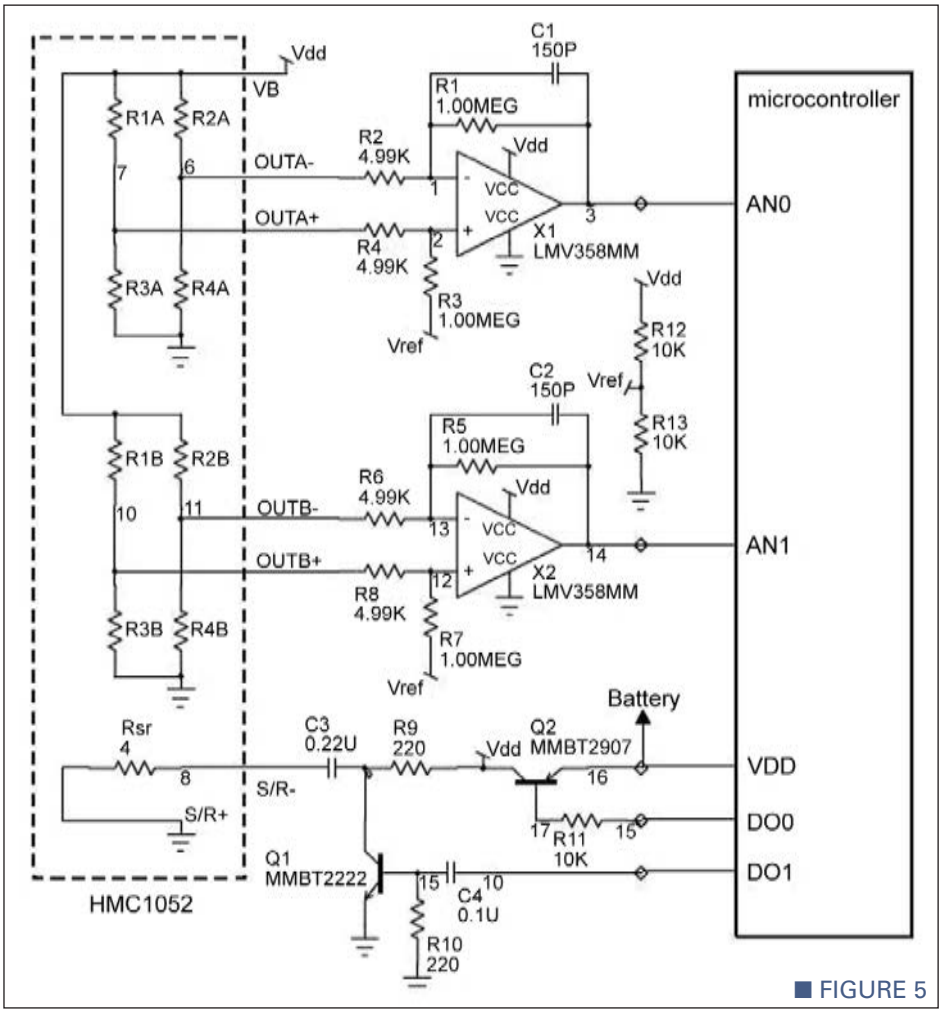
■ FIGURE 3



■ FIGURE 4

first pulse loads a one into the first cell of the register and at the same time resets the flip-flop (IC1, A and B). Take a look at Figure 4. I used all four of the NOR gates because they were there and also to give some added delay to insure that the J/K input is one when the clock goes high. The capacitors, C1 and C2, are to debounce the mechanical switches. The resistors, R1 and R10, provide an initial low level to the inputs. The first pulse lights LED D1; subsequent pulses shift the lighted LED to D2, D3, and D4. The last pulse leaves one of the LEDs lighted and it stays that way until the reset button is pressed. Almost any NPN will work for the transistors; 2N3904 or PN2222, for example.

A fault with this circuit is that if a second alarm comes in and the reset button has not been pressed, then the lighted LED will be shifted giving an erroneous indication. It may be shifted out of the register, leaving all the LEDs unlighted. For that reason, I added an LED to the IC1D output which indicates that an alarm happened and the reset button needs to be pressed. If desired, a time delay could be initiated from the IC1D output which would automatically reset the flip-flop.



■ FIGURE 5

MOTION DETECTORS

Q Could you explain the theory of operation of motion detectors (sensors)? Is it based on infrared or ultrasonic devices?

— Karas

A Both infrared and ultrasonic motion detectors are available. The infrared detects the heat of the human body, so motion is not actually required. Ultrasonic systems use the Doppler Effect where the frequency of the reflected wave increases when an object moves closer and decreases when the object moves away. A disad-

vantage of the ultrasonic system is that it could detect a branch or bush waving in the wind. You will find info on infrared at **www.glolab.com/pirparts/infrared.html**.

You will find a schematic, layout, and parts list here to build your own ultrasonic motion detector: **http://web-ee.com/Schematics/Motion%20Detector/UltrasonicMotionDetector.pdf**.

More info on ultrasonic can be found at **www.electronickits.com/kit/complete/surv/ck203.pdf**.

SURVEILLANCE SYSTEM

Q A friend of mine asked me to install a security camera in his store so he can watch the store from his home which is about 15 km away. I know I need a camera and monitor, but how is the signal transmitted from the camera to the monitor?

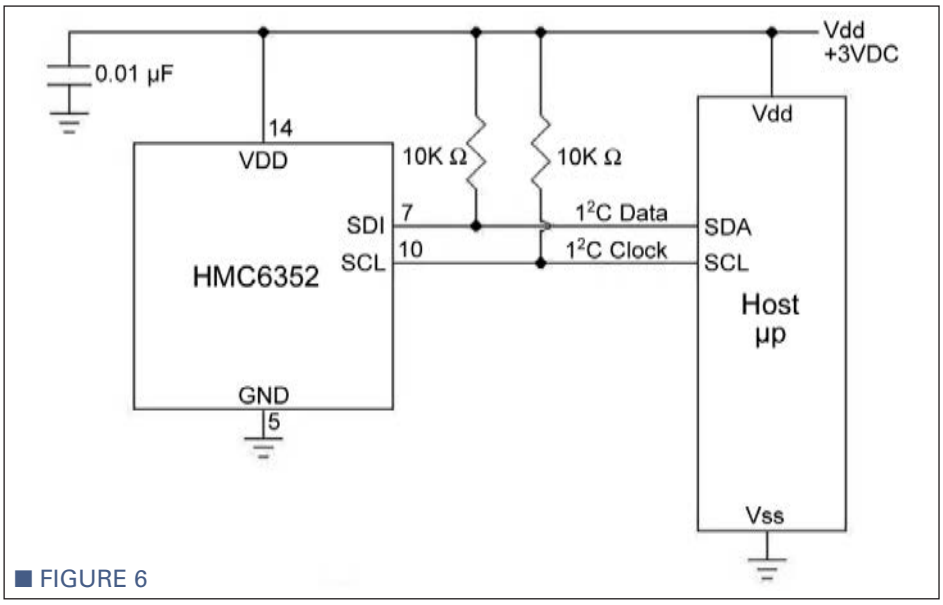
— Tom Karas

A An RF link would not be reliable; video has been sent over telephone lines but that system never took off. Video is sent over the Internet now and that is the way to go. You could use an inexpensive web cam like this one **www.x10.com/key_products/internet-surveillance.htm** for a low cost system. Or else you could purchase a complete system, as provided by these sellers: **www.ramelectronics.net/html/X-Guard.html**, and **http://webcam-software.net/webcam-software.htm**.

Their lowest cost system supports four cameras, but it is not necessary to use them all. Another alternative is to buy the components and build the system yourself; here is one supplier: **www.youdoitsecurity.com/Remote-Surveillance-Equipment.asp**.

Your minimum system will consist of: video card, camera, and software, plus two computers — one at the store and another at the home. All the systems above come with bundled software. You will need a high speed Internet connection (not dial-up) to have streaming video. I think DSL will work; check with the supplier.

Check the index and back issues of *N&V*; you will find some camera bargains there.



■ FIGURE 6

DIGITAL COMPASS

Q I'm looking for any suggestions for a cheap digital compass, ranging from an analog voltage value of 0 to 5V, for 360 degree pointing.

— de KJ4UO

A *For those not in the know, de is used by Morse code operators; it is the French word "from."*

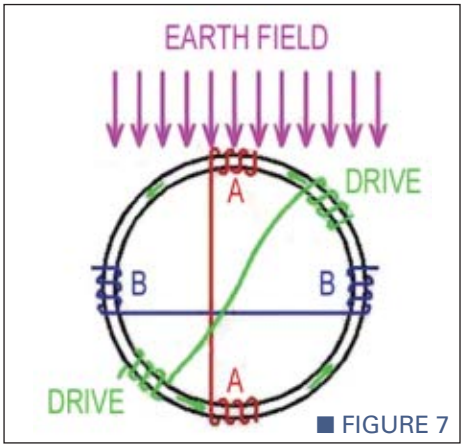
Many modern compasses use Honeywell HMC1051/1052 magnetically sensitive resistive bridges. One bridge is oriented North-South; the other is East-West. The outputs are amplified and fed into a microprocessor which calculates the direction. Figure 5 is taken from the HMC1052 datasheet. Figure 6 is an even simpler schematic of the HMC6352 which has the op-amps and microprocessor in it. The Honeywell application note AN914 has the HMC1052 information, and the HMC6352 datasheet is found at: **www.ssec.honeywell.com/magnetic/datasheets/HMC6352.pdf**.

A truly simple compass can be made using the 1490 compass from **www.imagesco.com/articles/1490/01.html#top**.

The compass uses the Hall Effect and only has 45 degrees resolution, but you can't beat it for simplicity. The 1490 has 12 pins: four of them are VCC, four are GND, and four are outputs. The outputs are capable of 20 mA and can drive an LED directly. See the URL.

The only digital part of a digital compass is the microprocessor that does the calculation; the sensor is necessarily analog. Another type of sensor (which I could not find on the web) is the fluxgate. Figure 7 is a depiction, not necessarily how to make one. Note that the coils A and B are wound in opposition so the drive signal cancels out. The drive signal is AC. The drive and earth magnetic fields on the left side add while the fields on the right side subtract.

Since the coils are wound in opposition and the field on the left is increasing while the field on the right is decreasing, the signals add producing maximum output. The coils are wound on a high permeability toroid, either tape wound or ferrite. If the winding is carefully done, the output will be sinusoidal as the toroid



■ FIGURE 7

is rotated in the earth's field.

In any of the compasses, it is necessary for the sensor to be horizontal or aligned with the earth's field. Compensation for declination is done in better compasses but near the north magnetic pole, the declination is so near 90 degrees that a gyrocompass is needed to supplement the magnetic sensor.

For those wanting to build a good digital compass, I recommend Microchip's application note AN996, which you will find at **http://ww1.microchip.com/downloads/en/AppNotes/00996a.pdf**. The compass is designed around the PIC18F2520 and you can download the schematic and program. There is also a map of the earth's field which will be useful to anyone using a compass. **NV**

MAILBAG

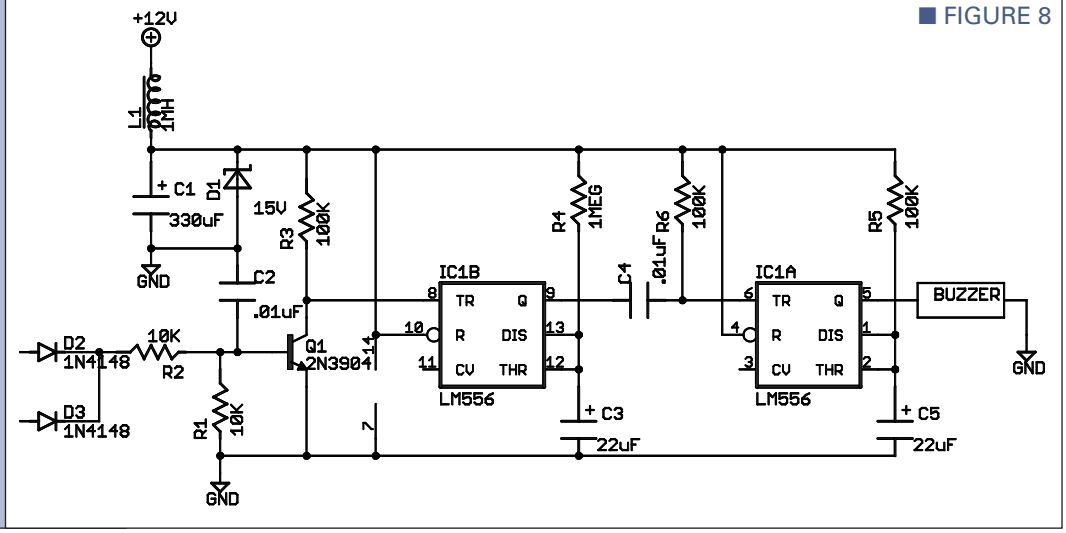
Dear Russell,

I have not been successful in getting the turn signal reminder from July to work, even after re-checking. It won't shut off. Did you build the unit and check it out? If so, do you have any changes to the circuit in the October issue?

— FMC

Response: *Thanks for writing. I did not build it but I have simulated the circuit and see the problem. The second 555 trigger is left low when the blinker stops, which makes the output stay high. The solution is to put an R-C between the two 555s as in Figure 8. Mea culpa!*

FIGURE 8



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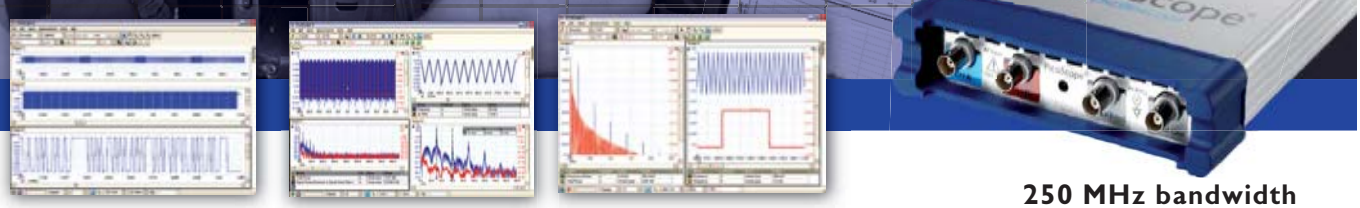

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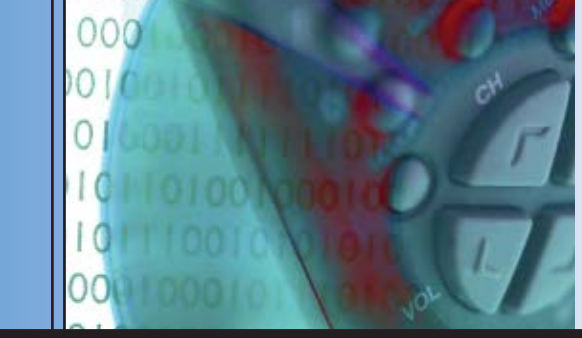

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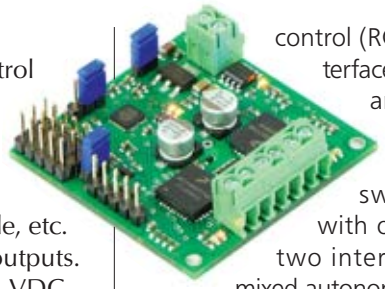

Pololu introduces its new TReX Jr Dual-Motor Controller, a versatile DC motor controller suited for mixed autonomous and radio control of small- and medium-sized robots. Three independent interfaces are offered: radio control (RC) servo pulse interface, analog voltage, and asynchronous serial. The serial interface can switch instantly with one of the other two interfaces, allowing mixed autonomous and remote control. For example, a robot could be configured to run autonomously most of the time, but a human operator could override the autonomous function if the robot gets stuck or into a dangerous situation. If the serial mode is selected as the primary interface, high-resolution measurements of all five RC inputs are made available to the autonomous robot controller, allowing for complex and unlimited mixing of operator control and sensor input.

The TReX Jr motor controller operates from 5 to 24 V, and the two primary outputs provide bi-directional control with peak currents of 5 A and continuous currents of 2.5 A while a unidirectional auxiliary output delivers over 10 A (continuous). A fourth control channel for invertible robots allows improved control if the robot does get turned upside-down, and the fifth control channel determines which interface controls the motors. The unit measures approximately 1.75" x 1.75" x 0.5", and it is available fully assembled or in kit form.

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TALK BACK TO YOUR NUVI®

Garmin International, Inc., has announced the new nuvi 880, a premium portable navigation device with cutting-edge speech recognition, dynamic MSN Direct content, and an impressive array of other convenience and safety features.

The nuvi 880's speech recognition technology is simple and intuitive to use. Users mount a push-to-talk wireless remote to their steering wheel, which is used to activate voice commands — no additional setup or training is required. Once activated, the user can effortlessly manipulate controls by speaking the words that correspond to buttons that are on the touchscreen display, so that almost any common task can be performed without ever touching the unit.

Garmin has also streamlined the way users can perform complex points of interest searches. Use a voice command to select the establishment of choice, and the nuvi 800 series gives turn-by-turn directions. The nuvi 880 also knows the names of many large business brands, so a user need only say, "find nearest Starbucks" for a quick caffeine fix.

Speech recognition can also be used to search for addresses as well — all hands-free, from start to finish. Speech recognition is available for American English, British English, European French, European Spanish, German, Italian, and Netherlands Dutch languages.

The nuvi 880 also provides next-generation dynamic content from the MSN Direct network, including:

• Traffic conditions — Receive up-to-date traffic incident and flow information for most metropolitan areas across North America, and let nuvi select a route that avoids traffic accidents, road closures, and construction.

• Fuel prices — Receive gas price data from over 100,000 gas stations across the nation. Drivers will always know where to get the best prices — and save time and fuel by using their unit to navigate directly to the station of their choice.

• Weather reports — Features current weather conditions (including high/low/current temperatures, chances of precipitation, humidity, pressure, wind, and weather alerts), as well as three day weather forecasts.

• Enhanced movie listings — Search for movies by title or by theater and receive show times, star ratings, genre, actors, and more — and get driving directions to the theater.

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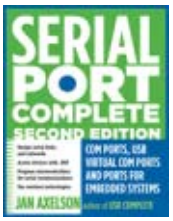

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The nuvi 880 has Bluetooth wireless technology for hands-free calling when paired with compatible phones. Using the unit's speech recognition capabilities, users can find and dial phone numbers (specifically supported phones can even access their history log of received, missed, and dialed calls) or nuvi's points of interest database (hotels, restaurants, stores, and more). This new premium PND also has a built-in FM transmitter, allowing users to wirelessly transmit turn-by-turn directions and street names, MP3s, and audio books through their vehicle's stereo. The nuvi 880 has front-firing stereo speakers and a removable lithium-ion battery.

The unit features a bright, sunlight-readable 4.3-inch color touchscreen display (480x272 pixels), and the nuvi 880 is loaded with maps of the US, Canada, and Puerto Rico. The new unit incorporates a high-sensitivity internal GPS antenna that makes it thinner and easier to mount in a car. Turn-by-turn, voice-prompted directions guide drivers to their destination, announcing streets by name along the way. If they miss a turn, the nuvi automatically recalculates a route and gets them back on track.

To help drivers find their car in an unfamiliar spot or crowded parking lot, the unit automatically marks where it was last removed from the windshield mount. Users can save 10 routes, specify via points, and preview simulated turns, and the unit automatically sorts multiple destinations to provide an efficient route for errands, deliveries, or sales calls. It also displays speed limits for highways and interstates, and a trip log provides an electronic bread crumb trail of up to 10,000 points.

The nuvi 880 includes many entertainment and travel tools including a music player (MP3, Ogg, and Flac formats supported), audio book player (subscription to Audible.com required), alarm clock, picture viewer, currency converters, and more. The units also are installed with Garmin Lock™, an innovative patent pending theft prevention system that disables the unit from performing any functions until the user types in a specific four-digit PIN or takes the unit to a predetermined secure location.

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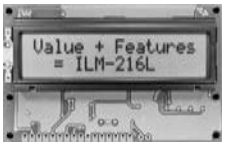

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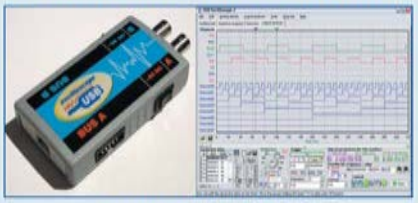

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FOLLOW THE FLASHLIGHT EVOLUTION

Using just a few components, you can easily transform the traditional bulb flashlight into an energy-saving, super bright LED flashlight.

During recent years, with the advent of white LEDs, the ubiquitous household item — the traditional incandescent flashlight — is experiencing radical changes.

It caught my attention when I noticed the many benefits LEDs can bring about; especially their energy-saving efficiency and the much brighter luminous intensity.

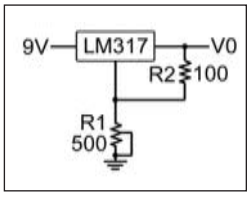
I started to think about and work on how to transform all of my traditional bulb flashlights into LED flashlights. The outcome actually turned out to be quite encouraging and rewarding, and the costs were minimal. I'd like to share some of my experiences with you here.

White LED Parameters

The main players in this flashlight evolution are the white LEDs. They are the newest members in the LED family, and super bright white LEDs are still expanding.

White LEDs differ from the normal signal indicator LED in several ways, but the most important parameters are these three: forward voltage V_F; the corresponding forward current I_F; and luminous intensity measured in millicandela (mcd).

Most white LEDs are typically listed as V_F = 3.2-3.6V, I_F = 20 mA; their luminous intensities can range from 3,000 to 30,000 mcd with associated ascending prices. For our purposes here, most 6,000 to 9,000 mcd LEDs are adequate.



■ FIGURE 1. Regulated power supply for LED testing.

Also keep in mind that not all LEDs are created equal. Even if you buy the same batch of LEDs from one source, each LED may have slightly different forward current under the same forward voltage; hence, different brightness.

For this reason, it's better to measure each LED's V_F and I_F before using them. Figure 1 is the simple regulated power supply circuit to do so. It uses the LM317 regulated IC. Its output voltage V_O (volts) can be approximately calculated by the following formula:

EQUATION 1:

$$V_o = 1.25\ (1 + R1/R2)$$

For instance, using R1 = 500Ω trimmer potentiometer and R2 = 100Ω, the highest output voltage should be V_O = 1.25*6 = 7.5V. Therefore, you can reduce the trimmer resistor value to get any regulated voltage between 3.0V to 4.5V at the output for your experiment.

My First LED Flashlight

My first LED flashlight was a very simple one. I didn't change

anything except the burnt-out incandescent light bulb. I didn't hesitate at all to crack this burnt-out bulb and solder a V_F = 3V, I_F = 10mA white LED in its place to the remaining two whisker electrodes of the bulb (Figure 2).

The labor was absolutely minimum since the only thing I had to take care of was soldering the LED's anode pin to the bulb's anode whisker.

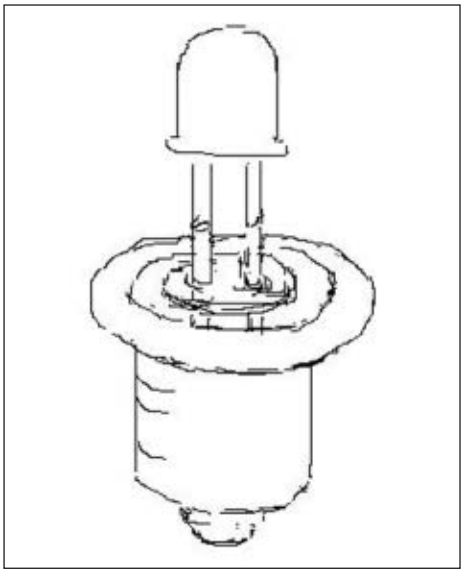
The brightness of this single LED isn't really comparable to the original bulb, but it's still useful at night and only consumes 3V*10 mA = 30 mW (as compared to the original bulb at 3V at 500 mA = 1,500 mW — an energy savings of 50 times!).

Before making this particular LED flashlight, I searched on the Internet to see if there were 3V 20 mA LEDs. Even though the difference is only 10 mA, this specific requirement is important because most household flashlights use 3V battery cells, and the LED's brightness is roughly proportional to its current. So, a higher current rating would double the brightness.

I found only one manufacturer who offered such an LED. The datasheet listed it as typically 3.0V at 20 mA. So I purchased 15 of them from a distributor. Unfortunately, after testing them, I found that none of them reached 20 mA at 3V. All 15 pieces only had the same 10 mA at 3V. When I questioned this on the company's website, their engineer admitted it was a "datasheet error." (Very frustrating!)

Make it Brighter — Parallel Three LEDs

The straightforward way to increase brightness is to connect LEDs in parallel. The brightness more than doubled (90 mW). I did have to use a small perfboard to solder the three LEDs in parallel; the subsequent supporting and connecting mechanism between the battery and the board also had to be addressed. This second LED flashlight was better than the first one, but it was still not brighter than the original.



■ FIGURE 2. This is the easiest way to make an LED flashlight.

In order to outperform the traditional flashlight in brightness, the battery voltage would have to be raised to more than 3V. That's why most of the commercial LED flashlights use 4.5V batteries (three AA or AAA cells). I happened to have a fancy 4.5V bulb flashlight that contained a battery compartment for three AA cells. The bulb consumes 300 mA at 4.5V, or 1,350 mW. Such huge current is not good for battery longevity, so I wanted to change it. This seemed to be the best place for using 3.5V, 20 mA LEDs.

One problem that must be solved is the voltage gap between the 3.5V LED and 4.5V battery. I have seen some commercial LED flashlights where the 4.5V battery voltage is directly applied to the parallel 3.5V LEDs. That's not a good engineering practice. It will overtax the LEDs and shorten their life.

The simplest solution is to add a current limiting resistor. As shown in Figure 3, this resistor is in series with three parallel LEDs. While each LED consumes 3.5V at 20 mA, the resistor Rs consumes the remaining 1V at 60 mA, so Rs = 1V/60 mA. Choose a close nominal value of 15Ω — that's the main design of my third LED flashlight.

This flashlight (Figure 4) looks much brighter than the original one. Its total power consumption is 4.5V*60 mA = 270 mW — only 1/5 of the original — so with this smaller current, the battery life will be several times longer, and higher lighting efficiency is achieved.

Nevertheless, we should note that resistors do waste some energy to protect the LEDs. In this example, there is always 1/(4.5) or 22% energy waste to resistance heating. The utility efficiency is 78%. We'll see how to deal with this problem later.

■ FIGURE 3. Parallel three LED flashlight with a current limiting resistor.

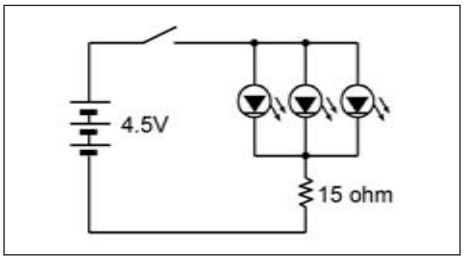
Digital Flashlight Design Experiment

I use the phrase "digital flashlight" to categorize any flashlight that contains a microcontroller (MCU). Of course, digital flashlight, must use LEDs, but an LED flashlight is not necessarily a digital one.

Figure 5 is the circuit for a digital flashlight design experiment. It contains only a few components in addition to the LEDs. Let's draw some guidelines from this experiment. Note the supply voltage is 4.5V, and the interrelated component values are already chosen for the best fit. The LEDs are connected in serial instead of parallel.

Basically, the circuit is a voltage booster or step-up switching voltage converter, which converts the 4.5V supply to higher voltage for the serial LEDs. The number of LEDs should be two or more.

The circuit uses ATtiny11 (U1) as a charge pump and operates as follows.

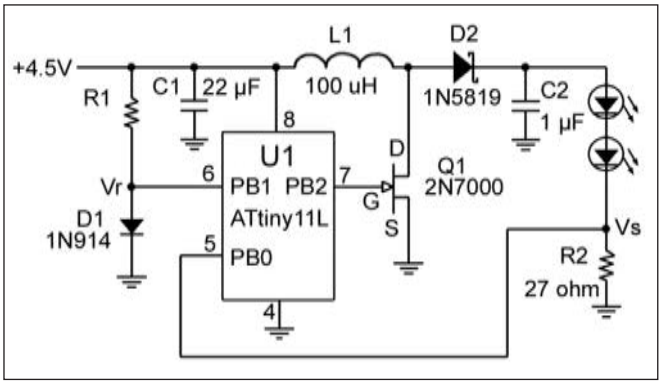


■ FIGURE 4. This three LED flashlight looks much brighter than the original incandescent one.

When the MCU outputs a logic high to the gate (G) of the 2N7000 N-channel MOSFET, it turns Q1 ON between drain (D) and source (S), hence the right side of inductor L1 is shorted to ground. During this period, the 4.5V power supply charges L1 so that its current increases from zero to a peak value of I_{pk} linearly (Figure 6), as long as the inductor is not saturated. (That's why choosing the right inductor is important; see the Source information later.)

Next, the MCU outputs a logic low and Q1 turns OFF so the current can't flow to ground; however, the inductor's stored energy will induce a high voltage to keep current flowing. So, Schottky diode D2 conducts and the capacitor C2 is charged until the current becomes zero. The LEDs will be turned ON when the capacitor's voltage reaches the LED's total forward ON voltages.

■ FIGURE 5. Digital flashlight experiment circuit.



Because microcontrollers are widely available and inexpensive, plus have a small footprint, using them in LED flashlights is attractive. This is particularly true for the Atmel eight-pin ATtiny11L, which works down to 2.7V and costs only 52 cents each [1]. Listing 1 shows the assembly program used here for the MCU as a charge pump.

This program is so simple that it takes only 26 bytes of program memory. The most important idea is the charge pump control function. The instruction '**Sbi portb, 2**' tells the MCU to output a logic high to turn on the charge pump. Because the MCU works at 1 MHz by its internal oscillator, each NOP takes 1 µS to execute, so the ON time is Ton = 7 µS. Similarly, '**Cbi portb, 2**' tells the MCU to output a logic low to turn off the charge pump.

Instruction '**sbis ACSR, 5**' needs a little more explanation. First, **sbis** means "skip next instruction if bit# is set." Here the bit number is bit5 of the MCU internal register ACSR; its full name is Analog Control and Status Register. Bit5 is the comparing output of the ATtiny11 analog comparator pins PB0 and PB1.

Refer back to Figure 5. ATtiny11L has two analog input pins: PB0 and PB1, where PB0 acts as variable input V_s, while PB1 is set up at a fixed reference voltage; in our case, it's set to V_r = 0.6V by Silicon diode 1N914. If, and only if, V_s is equal or larger than V_r, bit5 of ACSR is set, so the charge pump will not turn on, but stay idle. Otherwise, it will keep charging for 7 µS every cycle. Because R_s = 27Ω, when V_s = 0.6V, the current-flowing LEDs will be I = 22 mA; that's the normal LED forward ON current.

Figure 6 illustrates the charge pump current versus time. There are two formulas that govern the circuit operation. The first one holds the relationship between supply voltage Vin, inductor L, its peak current I_{pk}, and MCU's ON time, Ton:

EQUATION 2:
Vin = LIpk/Ton

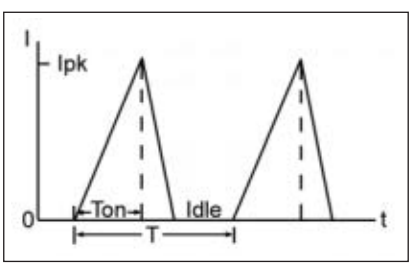
For instance, from V_{in} = 4.5V, L = 100 µH, I_{pk} = 300 mA, we can calculate T_{on} = 7 µs. This is exactly what we chose for the charge pump ON time in the program CPUMP.ASM, shown in Listing 1.

The second formula describes the power of the voltage booster related to inductor L, peak current Ipk, and its switching frequency f:

EQUATION 3:
$P = 1/2\ L(I_{pk})^2 * f$

Therefore, without changing component values, the circuit's switching frequency f will increase when adding more LEDs, because adding more LEDs means adding more power to light them up. You can easily test the correctness of this formula. For example, if you change the number of LEDs from two to four and measure the switching frequency in each case, you will get the frequency ratio = 2. In my experiment, I actually got f2 = 15 kHz, f4 = 31 kHz, respectively.

However, when the number of LEDs equals five or more, measurements indicates that V_s always becomes less than 0.6V. That means V_s



■ FIGURE 6. Charge pump current versus time.

can no longer keep up with V_r for more LEDs. Why? The reason is that the energy stored in L has all been used up or exhausted. The frequency had been increased to its highest possible, so that in Figure 6, "idle" time becomes zero. So, even though the charge pump continues to work every cycle, there will be no more energy than its maximum delivered to the LEDs.

In other words, when the number of LEDs equals five or more, we can safely remove the MCU's analog comparator circuit components R1, D1, and R2, without having to worry about the LEDs being overdriven. This is an advantage. Remember, R2 also wastes some energy (heat), although it is needed as a voltage sensing component.

LISTING 1. Program for ATtiny11L as charge pump.

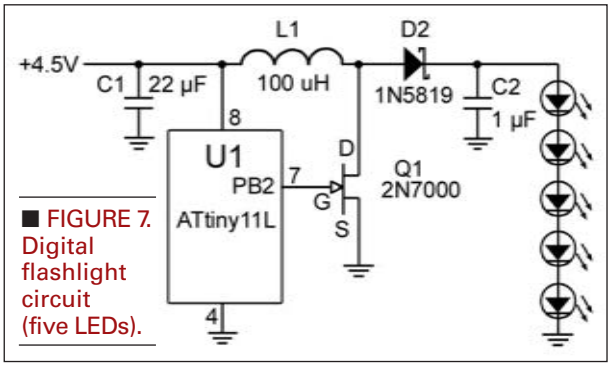
```
;CPUMP.ASM: control FlashLight LEDs uisng ATtiny11L at 1 MHz
;When Voltage boost pump ON=7 NOPs, Ton=7us

.include "TN11def.inc"
.cseg
.org 0
;-----------------------------------------------------------------
Start:
        sbi     ddrb, 2         ; make Portb.2 an output
        Cbi     portb, 2        ; pump=OFF to begin
Again:
        sbis    ACSR, 5         ; skip next instruction if Vs=>.6V
        Sbi     portb, 2        ; pump=ON for 7 NOPs (7uS)
        nop
        nop
        nop
        nop
        nop
        nop
        Cbi     portb, 2        ; pump=OFF
        rjmp    Again
;-----------------------------------------------------------------
```

Serial 5-10 LED Digital Flashlight

Because V_s cannot follow V_r when the number of LEDs equals five or more, so we can remove some components from the circuit without having problems, as shown in Figure 7. Correspondingly, we should also remove the instruction '**sbis ACSR, 5**' from the software, since the analog comparator is no longer used. This new program is now called CPUMP1.ASM and it takes only 24 bytes.

We can use this new circuit hardware and software program to build any 5-10 LED digital flashlight. As an example, I built a nine LED flashlight on the base of another flashlight that had a bulky body and reflector (Figure 8).

The control circuit contains only six small components that were mounted on a perfboard that measured less than one inch square. The nine LEDs were soldered on another circular perfboard. Before final assembling and gluing them in the body, the whole circuit must be connected together and tested to avoid any errors.



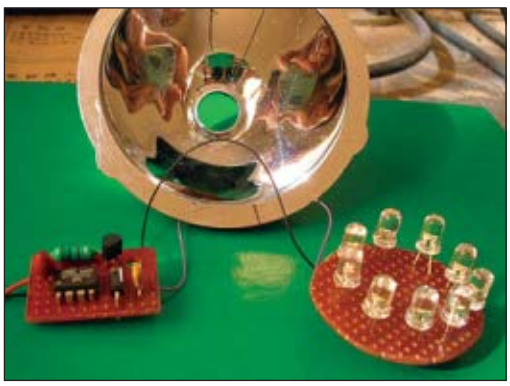
■ FIGURE 7. Digital flashlight circuit (five LEDs).

This is the fourth flashlight and it is super bright. The 4.5V (three AA cells) battery supplies 150 mA current, and the nine LEDs output 30V at 20 mA. The input power is 675 mW, output power is 600 mW, and the circuit efficiency is pretty high: 88%. The main reason is that in this case, there is no resistor used, and the ATtiny11 takes only 2-3 mA.

Summing Up

I now have four LED flashlights, all transformed from traditional bulb lights (Figure 9). All new versions are much better than the original in

■ FIGURE 8. The nine LED circuit and reflector before assembly.



■ FIGURE 9. These LED flashlights are all transformed from the traditional bulb flashlights. Depending on the number of LEDs and the applied voltage, their brightness varies from low (right) to high (left).

ITEM	DESCRIPTION
❑ C1	22 µF 16V Tantalum Capacitor
❑ C2	1 µF 35V Ceramic Capacitor
❑ R1	100K, 1/8W Resistor
❑ R2	27Ω, 1/8W Resistor
❑ D1	1N914 Diode
❑ D2	1N5819 (40V) Schottky Diode
❑ L1	100 µH 550 mA Conformal Coated Inductor
❑ Q1	2N7000 N-Channel MOSFET
❑ U1	ATtiny11L Microcontroller (programmed)
❑ LEDs	White LEDs (6,000 mcd or higher) at 3.5V, 20 mA

energy savings, and the last two versions outperform their predecessors in brightness. In addition to household use, the last two can be used for camping or for an emergency light. The use of a microcontroller improves circuit efficiency.

In order to minimize my work, I used all the original mechanical parts as much as possible, so no switches or reflectors had to be replaced; even the original battery holders were kept intact.

As a by-product, the boost voltage technology learned here can be applied to other fields. For example, most MCU programmers require 12V for the Flash memory programming. Now you know it's easy to get it from a USB port 5V power supply by using this boost voltage technology.

I like the power my LED flashlight has in the dark. It makes me think back to when our ancestors discovered fire and invented lights. LED flashlights are just a snippet in history. **NV**

[1] G.Y. Xu, "Programming the 52 cent Micro," *Nuts & Volts*, February 2006.

Sources for Components

■ For MOSFETs, inductors, capacitors: **www.jameco.com**; especially the 100 µH inductor (Jameco part #642492)

■ For white LEDs and the 52 cent ATtiny11L: **www.digikey.com**

■ For surplus white LEDs, inductors: **www.bgmicro.com**

NOTE: The following is available from:

G.Y. Xu, P.O. Box 14681, Houston, TX 77021.

Programmed ATtiny11L (with CPUMP.BIN or CPUMP1.BIN; please specify when ordering) — $1 each. (Send payment in with a self-addressed stamped envelope for free shipping.)

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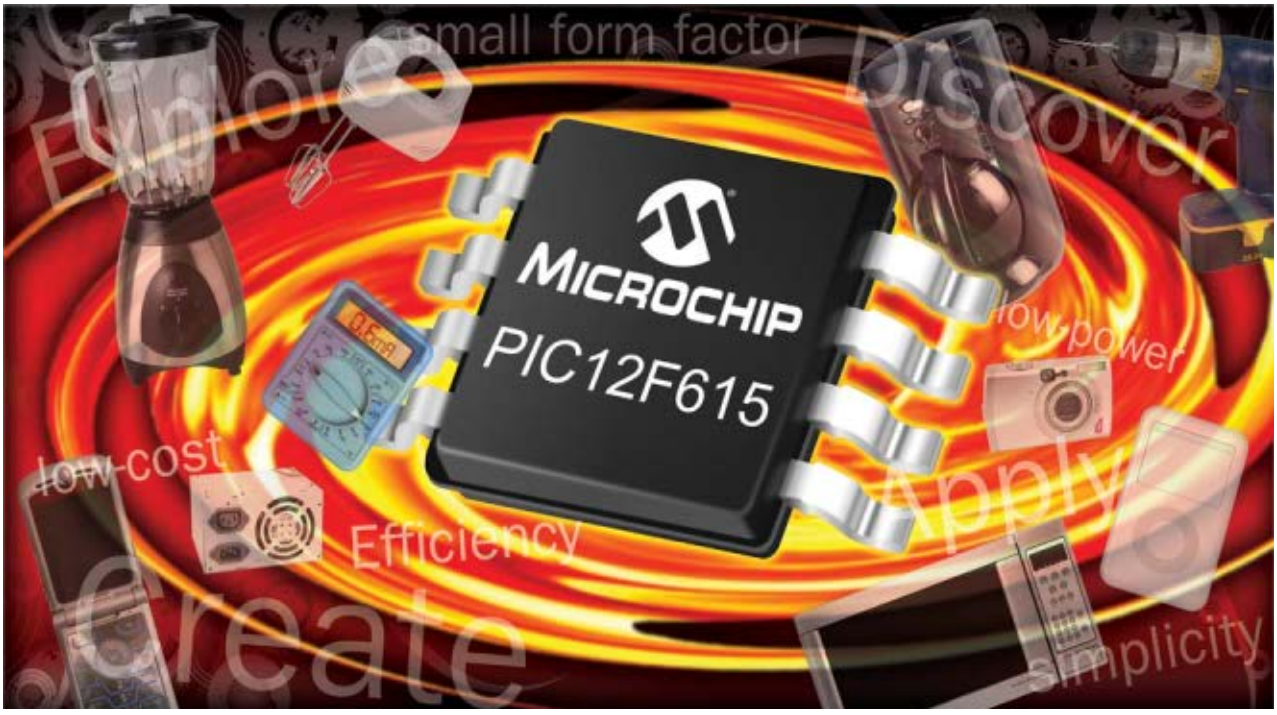

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PIC16F610*	1.75K (1K)	64	12	—	2	1-16 bit, 1-8 bit, 1-WDT	14 pin PDIP, SOIC, TSSOP, QFN
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A LOW COST RF IMPEDANCE ANALYZER

A voltmeter, signal generator, and a few parts combine to make a powerful impedance measuring tool.

Measuring the impedance of an antenna, a component, or a circuit such as a matching network, can often help us optimize our equipment and improve our understanding of its operation.

Commercial network analyzers, RF impedance meters, or antenna analyzers can do the job, but are out of the realm for many amateurs, especially since the equipment is expensive and would be sitting idly on the shelf most of the time. If we only need a few measurements, an old technique — the three voltmeter method — that uses a signal generator (or a QRP rig) and the ubiquitous digital voltmeter may fill the bill.

These items together with a few dollars worth of parts, a bit of software, and some manual work on your part can produce the data you need in just a few minutes. It also provides an easy, low cost way of acquainting yourself with the art of impedance measuring. While not as convenient as some commercial equipment, there is a satisfaction that comes with building and understanding a device that you have built yourself.

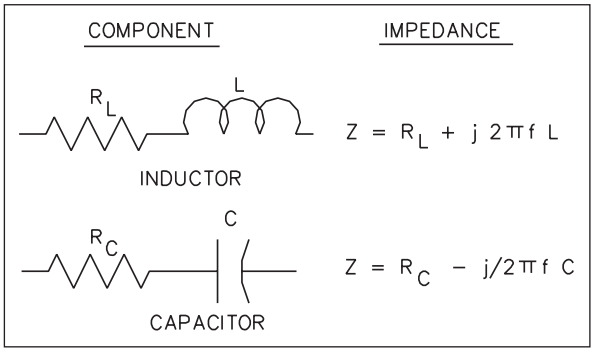
Discussed in this article are the details of this unusual RF impedance analyzer which uses a simple circuit with diode RF voltage samplers, as well as software for your PC that processes the data, compensates for the diode nonlinearities, and calculates the impedance, SWR, and other parameters of interest at frequencies up to 21 MHz or more.

This approach to impedance measurement has its limitations, but on the plus side, it is an easy project to build, is low cost, requires no power supply, and has the capability of producing results comparable to equipment costing much more.

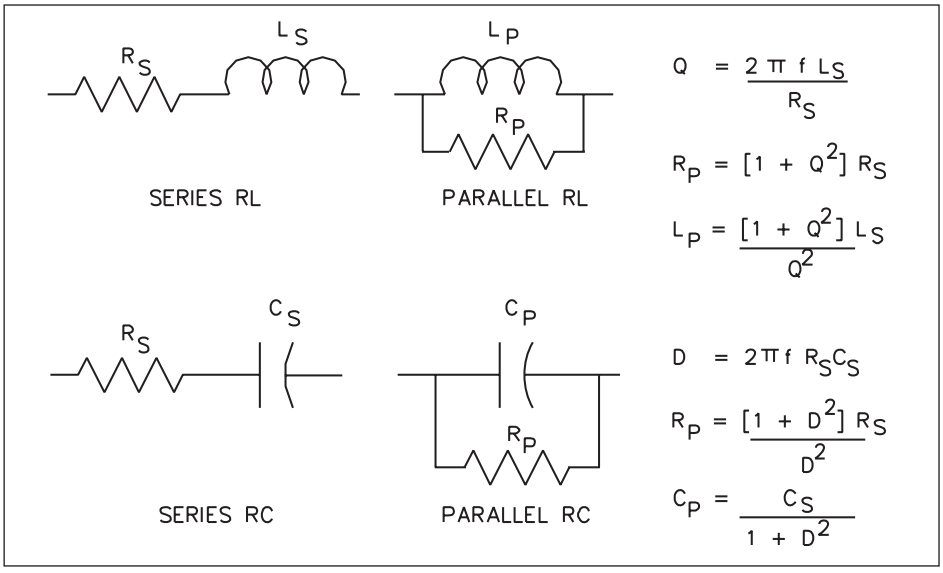
If you decide to build the project, you will need a PC running Windows®, a signal generator to cover the frequencies of interest with at least 13 dBm output into 50 ohms (about 1.414 peak volts or 20 mW), and a high input impedance digital voltmeter (DVM) with a DC accuracy of at least 0.5%. The circuitry is very low cost (less than $5) and uses readily available parts. I suggest that you build the circuit inside of a metal enclosure (not a solderless breadboard like I did) since that would limit your frequency range. To get started, let's review some concepts of impedance.

Impedance Models

Impedance is the more complete expression defining current flow than resistance



■ FIGURE 1. Lossy series models of inductor and capacitor. Frequency f, in hertz, resistance R, in ohms, inductance L, in henrys, and capacitance C, in farads.



■ FIGURE 2. Series and parallel equivalent circuit models at the same measuring frequency.

alone and is typically expressed as a complex quantity such as R + jX where R is the resistive part (real) and X is the reactive part (imaginary). The reactive part is usually frequency dependent and is preceded by the math operator "j" to indicate it is the imaginary part. For many resistors, the reactive part is very small, except for wire wound types. And so, it is typically ignored.

On the other hand, many inductors and capacitors are lossy (as seen in Figure 1) and have both a resistive and reactive part with the reactive part being positive for inductors and negative for capacitors. Measurements made on transmission lines and antennas also show both a resistive and reactive part which can be either inductive or capacitive, depending on the measuring frequency.

The models of Figure 1 show the resistive part modeled in series with the reactance. Another model is sometimes used with parallel resistors as shown in Figure 2. The series and the parallel models are equivalent at the same frequency of measurement and can be converted from one to the other using the equations shown on Figure 2.

The impedance analyzer software (discussed later) basically calculates the impedance in polar form from voltage measurements provided to it. This can be converted to rectangular form as shown in Equation 1:

EQUATION 1

$$Z = |Z| \angle \theta = R + jX$$

where Z is impedance in ohms, $|Z|$ is the magnitude of Z, θ is the angle of Z, R is the resistive part of Z, and X is the reactive part of Z. The two forms in Equation 1 are related by:

EQUATION 2

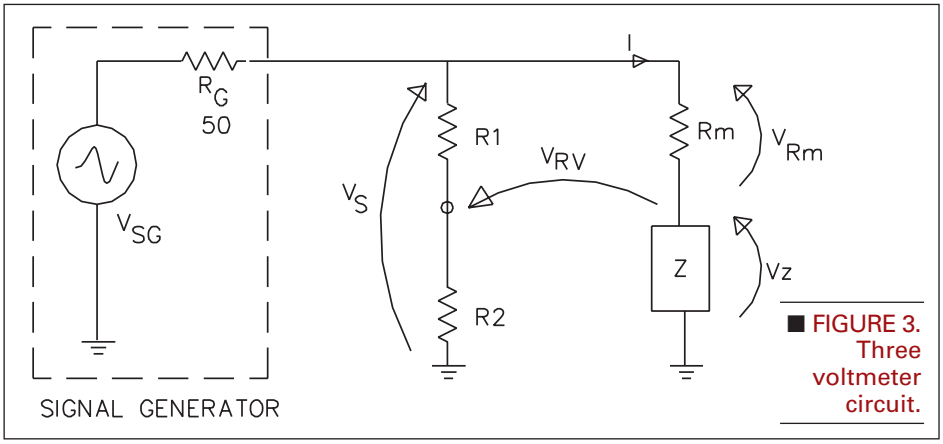
$$|Z| = \sqrt{R^2 + X^2} \quad \textit{and} \quad \theta = \tan^{-1}(X/R)$$

The impedance analyzer program will display the results in both polar and rectangular form on the computer screen. From here, it is relatively easy (knowing the measurement frequency) to calculate the values of the series and parallel models and to display them on the screen. Other parameters such as the Q (quality factor), or D (dissipation factor), SWR, and reflection coefficient are also calculated and displayed. Now let's see how to measure impedance in polar form using just a voltmeter.

Three Voltmeter Method

In recent articles [1, 2], I described a powerful method of measuring impedance at audio frequencies using a simple circuit and a computer with a sound card. Briefly mentioned was the "three voltmeter method" (TVM) as one technique that was looked at while working on the "least mean squares" (LMS) method which — by the way — was found to be superior. The LMS method would be preferred here too, but unfortunately it would be difficult and expensive to realize at higher frequencies. So the simpler TVM will be implemented here.

According to the grapevine, some antenna analyzers on the market today use an approach similar to the TVM described here and use a microprocessor for data collection. So, this article may give you some insight on how those units work, as well. The TVM is,



■ FIGURE 3. Three voltmeter circuit.

conceptually, very straightforward requiring only a single, precisely known resistor, a signal generator, and some voltage measurements. But underneath this simplicity, alas, lie problems of precisely computing small phase angles and maintaining accuracy at high SWRs. (We'll have more to say on this subject later on.) Nonetheless, the TVM is good enough to provide reasonably accurate and dependable results if you are aware of its limitations and don't expect extraordinary accuracy.

The TVM can be understood by referring to Figure 3, where V_{SG} and R_G represent a sine wave signal generator with internal 50 ohm impedance. Rm is the measuring resistor and Z is the load impedance. Resistors R1 and R2 shown in Figure 3 will be discussed later on. The voltages shown in Figure 3 are phasors and consist of a magnitude and phase angle such as $V_Z\angle\theta$ where V_Z is the magnitude and θ is the angle. The magnitude of the impedance Z is equal to V_Z divided by V_{RM} times Rm as shown in Equation 3:

EQUATION 3

$$|Z| = \frac{V_Z \times R_M}{V_{RM}}$$

To find the phase angle, use the current (I∠0) in Rm as reference and plot the three voltages V_{RM}, Vz, and Vs as shown in Figure 4 for some arbitrary Z. The angle θ is the angle of Vz with respect to V_{RM} and is also equal to (180 - ∠α) degrees. Cos(α) can be found from the law of cosines for triangle ABC. After some algebraic manipulations, cos(θ) is found in terms of the voltage magnitudes as shown in Equation 4:

EQUATION 4

$$\cos(\grave{e}) = \frac{V_S^2 - V_{RM}^2 - V_Z^2}{2V_{RM}V_Z}$$

We see from Equation 3 that the impedance calculation depends critically on the value of Rm, so it must be known precisely. But, as seen from Equation 4, the method is not able to distinguish the sign of the angle, since the cos(θ) = cos(-θ), so we must use other means to determine if the measurement is inductive or capacitive. Ways for doing this are discussed later on.

If we have a good AC voltmeter that can measure voltages without loading the circuit, all we need to do is measure the voltages shown and apply them to Equations 3 and 4. We also need a hand calculator, using the inverse cosine function, to find θ from the result of Equation 4. In the old days when measurements were made on 60 Hz power systems, this worked fine. But if we want to work in the high frequency range, most digital AC voltmeters won't measure AC voltages properly. Since the majority of us do not have a good RF, high impedance AC voltmeter, we will need another method of obtaining the voltages. A simple way of doing this is presented later on.

Before we leave this subject though, it should be mentioned that the SWR and reflection coefficient at the load can be calculated once Z∠θ is found. In this case, the reflection coefficient r can be found from:

EQUATION 5

$$|\rho| = \sqrt{\frac{(R-Rm)^2 + X^2}{(R+Rm)^2 + X^2}}$$

Here, R and X are the resistive and reactive parts of Z. The SWR can be found from:

EQUATION 6

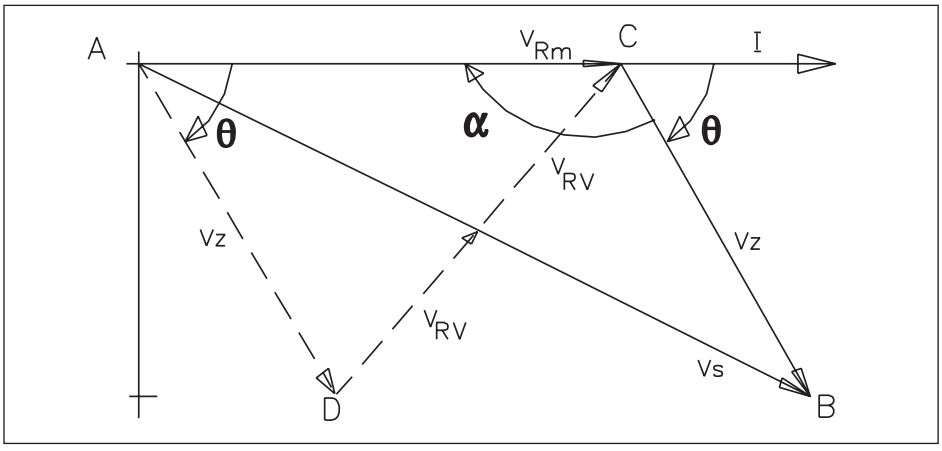
$$SWR = \frac{1+|\rho|}{1-|\rho|}$$

Note, too, that the reverse voltage V_{RV} shown in Figure 3 can be calculated from the three original voltages measured even without the two resistors R1 and R2 being present. To see this, refer to Figure 4 and note the triangle ADC where Vz and V_{RV} are shown dashed. The vector V_{RV} + V_{RV} goes from D to C and bi-sects Vs, if we assume R1 = R2. On the other hand, if we physically add the two resistors R1 and R2 to the circuit, we can measure V_{RV} and calculate V_S. This provides us with an alternate set of three voltage measurements and provides for the calculation of cos(θ) by means of another equation. This equation can be found by applying the law of cosines to triangle ADC to find cos(θ) from Equation 7 as shown below:

EQUATION 7

$$\cos(\grave{e}) = \frac{V_{RM}^2 + V_Z^2 - 4V_{RV}^2}{2V_{RM}V_Z}$$

The implications of this will be discussed in the next section.



■ FIGURE 4. Phasor diagram for circuit.

Understanding Accuracy and Phase Errors

The TVM produces a reasonably good result for the magnitude of the impedance (see Equation 3) since we should be able to measure the two voltages Vz and V_{RM} fairly accurately

and Rm is known precisely. Impedance errors will occur when either Vz or V_{RM} is very small, corresponding to large or small load impedances in which case the accuracy will suffer. Impedances near 50 ohms (where the voltages are roughly the same) and below an SWR of about 4:1 should be calculated fairly accurately.

Calculation of the cosine of the impedance angle θ is another story. Theoretically, Equations 4 and 7 would produce identical results. But practically speaking, there will be a difference depending upon the load impedance. What must be realized is that in a practical circuit there will be measurement errors and they will affect these two equations differently. Below is a numerical example to illustrate. More general comments follow the example.

Consider, as an example, a circuit such as shown in Figure 3, where R1 = R2 and Z = Rm = 50 ohms (corresponding to an SWR of 1:1 at the load Z). Assume the measured voltages are V_{RV} = 0.000 V, V_{RM} = 1.000 V, V_Z = 1.000 V, and V_S = 1.999 V (which has a negative error of 1 mV) since V_S would equal 2.000 volts in a system with SWR of 1:1. Calculating from Equation 4 yields cos(θ) = 0.998 while Equation 7 yields cos(θ) = 1.000 as it should. So, we have incurred an error of 0.2% with the first calculation and an error in the angle of 3.6 degrees but there was no error with Equation 7.

Note, too, that the error can conspire to make the cos(θ) >1, which is theoretically impossible for the cosine function. To illustrate, consider the above case with V_S = 2.001 V (a positive 1 mV error) and calculate cos(θ) from Equation 4 as 1.002.

Now consider the same example except that V_{RV} = 0.005 V (a positive 5 mV error) and V_S = 2.000 V (no error). Calculation from Equation 4 yields cos(θ) = 1.000 while Equation 7 yields cos(θ) = 0.9999. So, we have incurred only an error of 0.01% with the second calculation and an error in the angle of 0.81 degrees but with an assumed, much larger, measurement error.

Clearly then, as shown above, Equation 7 is less sensitive to errors for this particular case of a resistive load. Of course, this is not rigorous proof, but other examples at higher SWRs show a similar advantage. The author has performed a sensitivity analysis of cos(θ) with respect to V_{RV} and V_S in Equations 4 and 7, respectively. Sensitivity analysis refers to the sensitivity of a circuit parameter or value to errors in the component or some other value such as voltage. The mathematical details are too long to present here, but the results show that Equation 7 has the least sensitivity to errors when the load is resistive and at low SWR. Therefore, the circuit based on Equation 7 is chosen.

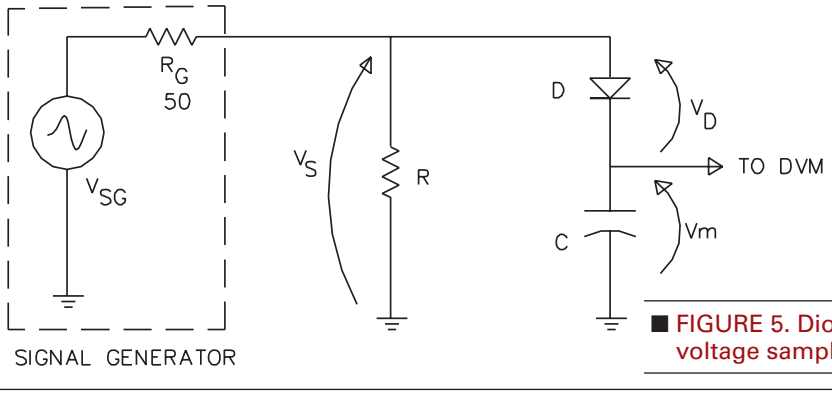
I hope that from the above discussion you can appreciate the importance of accurate measurements. As a further illustration, consider using an eight bit analog-to-digital converter (A/D) to measure the voltages in the above numerical example. Since we have a maximum voltage of two volts and 256 levels with an eight bit unit, each level corresponds to 7.81 mV. Clearly, only a one level mistake may cause a moderate angle error. On the other hand, modern digital multimeters have counts (levels) ranging from 2,000 to over 50,000 and 3-1/2 or more digits with 0.5% or better accuracy. This should provide a fairly economical and accurate means of collecting the voltage data. (More details are discussed later on.) Now let's take a look at how to measure the voltages required with an ordinary digital multimeter.

Diode Sampling Circuit

A circuit that is commonly used to convert AC voltages to DC for measurement is the "diode voltage sampler" (DVS) shown in Figure 5. In this case, we want to find the voltage V_S across R. Here's how it works. The positive, peak AC voltage across R is rectified by diode D and charges capacitor C. Once the capacitor is charged to about the peak value of V_S, it no longer places a load on R except for the minute amount of current needed to keep it charged. A high input impedance DVM can read the voltage on C which should be close to the peak value of V_S.

Of course, for maximum accuracy, we should add the value of the diode voltage drop V_D to the DVM reading Vm. If V_S is large, the diode drop is often neglected or considered a small constant of say, 0.7 volts, for a silicon diode. And as long as the diode voltage drop is small compared to V_S, this works reasonably well. But if V_S is smaller, say, 1.5 volts peak, the diode drop needs to be estimated better. And for even smaller voltages — as we might find in our impedance measuring circuit — it becomes critical to know the exact value of the diode drop to compensate our DVM reading.

A method that I have used with some success employs a mathematical model of the diode in the PC software. Knowing the diode parameters enables better compensation by using the model to estimate the diode voltage drop. Unfortunately, it is not perfect as it still leaves room for error due to manufacturing tolerances and capacitance effects. These errors can be ameliorated somewhat by calibrating the model with known



■ FIGURE 5. Diode voltage sampler.

impedances at specific power levels.

To see how the diode compensation works, refer again to Figure 5. Recall that the objective is to find an estimate of V_S from a measurement of Vm. This is done by estimating the diode voltage drop, V_D, and adding it to Vm, to form the estimate of V_S. To find V_D, consider the diode equation below:

EQUATION 8
Solving for V_D yields:

$$I_D = I_S[\exp(\frac{V_D}{NV_T}) - 1]$$

EQUATION 9

$$V_D = NV_T \ln(\frac{I_D}{I_S}) + 1)$$

where N =1, V_T = 26 mV @ 25°C, I_S = 22.31 x 10^{-9} A and I_D is the diode current, according to the Agilent Spice model on the 1N5711 datasheet. So, everything is known except for I_D which can be approximated by Vm/Req where Req is the equivalent impedance of the DVM or other resistive loads on the diode that we may add later. Since Vm is measured and Req is estimated, this is a good starting point to find I_D and, therefore, V_D. A better estimate for the diode voltage drop can be found by adjusting Req under known conditions such as a specific power level and known resistive load. More details on the calibration using known resistors is discussed later on.

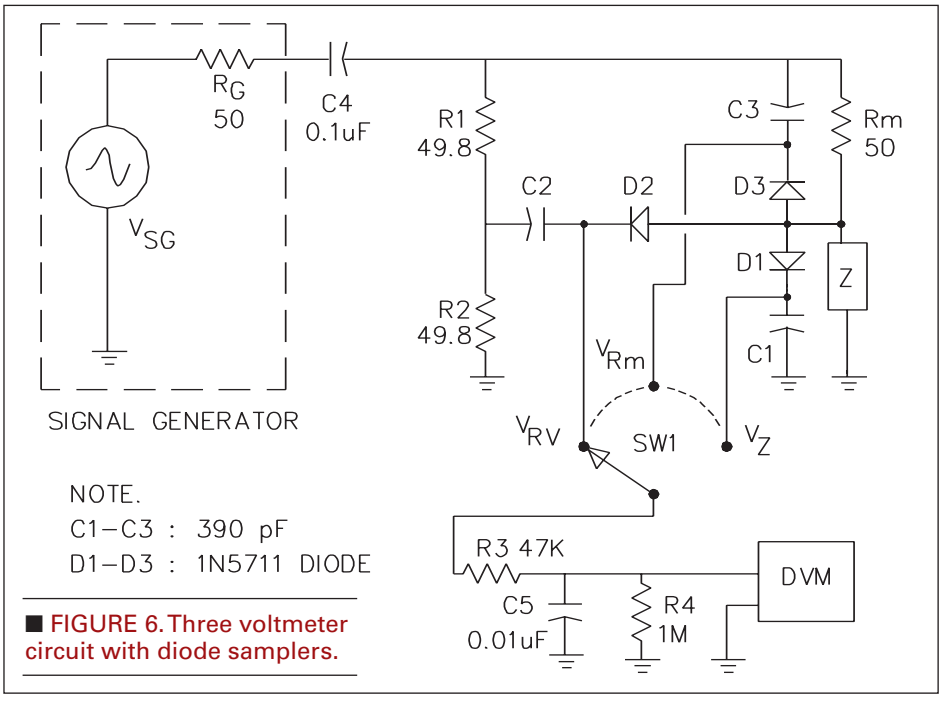
Another thing we can do to improve accuracy is to employ a fast switching diode that does not conduct substantially after the peak voltage has passed as that would reduce the capacitor voltage. Diodes meant for 60 Hz power supply use are not usually built for speed, and shouldn't be used in an RF peak detector. A Schottky diode (or barrier diode) like the SD101A, 1N6263, or 1N5711 are better options and also produce a low voltage drop. Germanium diodes like the 1N34 also have a low voltage drop but are prone to temperature and matching problems. I have found the 1N5711 to be a good choice and it is available from many sources for around $0.30 each.

Another effect that is hard to compensate for is the diode capacitance. For the 1N5711 model, the package capacitance can be 2 pF, which causes some bypassing of the AC signal around the diode. At 14 MHz, this bypass impedance can be as low as 5,600 ohms. Measurements made on the above sampler with a DC multimeter confirmed that the measured voltage tends to fall off with frequency.

The TVM circuit can be modified by adding a DVS across each resistor that has an AC voltage that we wish to measure. If the resistances are low enough (in the 50 ohm range) and the input impedance of the DVM is large enough, the basic circuit operation will not be affected substantially. To confirm this, I viewed the AC voltage across a 100 ohm resistor (in a circuit similar to Figure 5) with a Tektronix TDS360 digital oscilloscope when driven by a Wavetek Model 81 signal generator at 3.5 MHz.

No visible difference in amplitude was seen when the sampler was placed across the resistor. But what surprised me was that the scope probe (10 Meg and 15 pF) affected the voltage read by the DVM slightly, probably due to the probe capacitance. So, don't leave any probes connected to the circuit during impedance measuring!

There are a number of ways that the samplers can be added to the circuit of Figure 3. After considering several possible variations and testing for accuracy, the circuit shown in Figure 6 emerged as the best and was chosen for the final implementation.



■ FIGURE 6. Three voltmeter circuit with diode samplers.

RF Impedance Analyzer Circuit

Figure 7 shows my breadboard setup for the impedance analyzer. A BNC connector (shown on the right) is used to connect to the load Z. In this instance, I am using a solderless breadboard as it is an easy way to get started and confirm operation of the circuit. However, be aware that I am *not* recommending this construction method as it is limiting in terms of stray capacitance between components and has no shielding. Even though I used triple spacing between components on the breadboard, I started noticing frequency effects above 10 MHz.

Placing the circuit on a PCB (printed circuit board) with parts spaced apart and inside of a metal enclosure with the appropriate connectors and switch should be a better option.

Actually, it shouldn't be too complicated to build and it should make a nice weekend project as it is straightforward and there is no power supply needed.

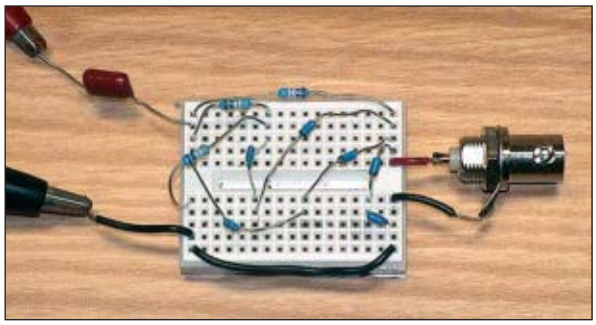
Now, refer again to the impedance analyzer circuit schematic shown in Figure 6. Only a few parts are required but they must be selected carefully for best results. D1 through D3 are 1N5711 Schottky diodes. It is best if they are matched. I bought 10 diodes which were packaged on a tape reel and chose three diodes that were placed together. Of course, this doesn't guarantee the diodes are matched, but it may improve the odds. Similarly, I bought 20 pieces of 49.9 ohm, 1/4 W, 1% resistors and carefully measured each one. I found one that was 50 ohms and used that for Rm.

I also found several resistors that were close to 49.8 ohms which were then used for R1 and R2. It is important that these two resistors be matched in value. I also matched the three capacitors C1 through C3, 390 pF, 5% ceramic capacitors which should be COG type. I also purchased some 12.5, 25, 100, and 199 ohm, 1/4 watt, 1% resistors for use in calibration.

Shown on the diagram are a coupling capacitor C4, a switch SW1, and filter components R3, R4, and C5. Tolerances of these components are not critical. R4 may or may not be required, depending on the input impedance of your DVM. This is discussed in more detail later on. SW1 is used to select the voltage for measurement by the DVM. Finally, you should choose the appropriate input and output connectors for the type of measurement you will make, be it a component or transmission line.

Signal Generator and Digital Multimeter Requirements

A sine wave signal generator with 50 ohm output impedance that produces a reasonable level is needed. Signal generators are usually rated in dBm output (for 50 ohm systems) which can be converted to peak volts, as needed. For example, 13 dBm output into 50 ohms produces 1V RMS, or about 1.414 volts peak. Although the generator will not always see 50 ohms, this is still a convenient reference point. Because of the diode nonlinearity, there is a lower limit of generator output where it becomes very difficult to compensate accurately for the voltage drop. This occurs somewhere around 13 dBm. I don't recommend using a generator with an output below this value.



■ FIGURE 7. Photo of breadboard setup of the impedance analyzer.

Unfortunately, some generators "max" out at 10 dBm (0.707 VRMS or one volt peak) and would produce marginal results. Several generators in my shack have that limitation. On the other hand, many generators can produce much more. My Wavetek Model 81, 50 MHz generator can produce up to 24 dBm (or five volts peak voltage).

Some generators produce a DC offset voltage which can cause the diode sampler to have an error. My Wavetek — although it was set for 0 volts offset — actually produced 6 mV offset, and while that doesn't sound like much, it was enough to cause errors. I cured the problem by placing capacitor C4 in series with the generator to block the DC voltage.

A QRP rig is probably over-powered for use as a signal generator for this application, so an attenuator must be used to bring the level down below 24 dBm. Attenuation of transmitters is beyond the scope of this article so you will need to consult an appropriate radio handbook.

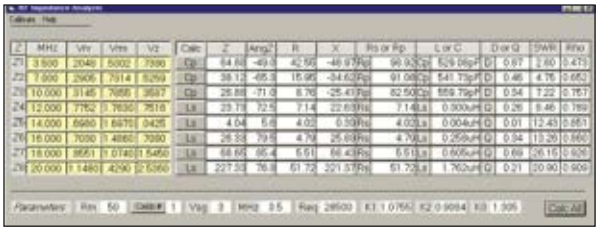
Digital voltmeters or multimeters are very common today. A basic DC accuracy of 0.5% or better is needed. Normally, when accuracy is specified in this manner it means 0.5% of span. So, if your voltmeter range or span is, say, two volts, then an error of 0.5% of two volts (plus or minus 10 mV) is still within specifications.

Of course, it doesn't mean you will necessarily see that large of an error. Many of the very low cost units are definitely not appropriate as they are rated above 0.5%. Some economical units can be found with an accuracy better than this. Unfortunately, a few meters may proclaim high accuracy but it may well be salesmanship on their part. Caveat emptor!

Multimeters can have quirks. As a case in point, an auto-ranging digital multimeter, with a stated accuracy of 0.3%, was obtained on the Internet for around $19. With the range fixed, it produced acceptable results but when in auto-range mode, produced errors as high as 40% on low voltages. Why? As it turns out, for the lower DC range, the meter's input impedance changes from 10 Meg-Ohms to over 100 Meg-Ohms. This causes a different loading on the circuit in Figure 6, with resulting higher voltages measured on the low range. This can be remedied by fixing the range so that it is not allowed to auto-range to the lowest span. This seems to work best with meters having higher counts.

Even high-end meters like the Protek 608 have different input impedances for different ranges. For example, on the 500 and 2,500 mV ranges the input impedance is greater than 1 Giga-Ohm. On the 5.0 to 5,000 volt ranges, the input impedance ranges from 10 to 10.5 Meg-Ohms.

If the input impedance is extremely high, looking at a capacitive load like C5 in Figure 6 may cause problems, so resistor R4 was added. It may not be needed in some cases, and if omitted, will allow a higher voltage to be measured. Note, too, that some DVMs have a low input impedance and are designed for special applications. An input impedance of at least 10 Mohms is needed here to prevent over-loading the diode voltage samplers. Be sure to check your meter for



■ FIGURE 8. Main window of the RF impedance analyzer program.

accuracy, try to avoid changing ranges, and watch out for auto-ranging mode.

For the record, four DVMs were tested in this project. They included a Kelvin 200LE (2,000 count, 0.5%), Gardner Bender GDT-193A (2,000 count, 0.5%), Circuit Specialist MY-68 (3,260 count, 0.3%), and a Protek 608 (50,000 count, 0.05%). The first three are low cost meters and produced acceptable results with the Protek producing slightly better results. I believe the calibration routine (discussed later) helps fine-tune the results for a specific meter and improve accuracy. So, if you change meters, you probably should re-calibrate the software.

RF Impedance Analyzer Software

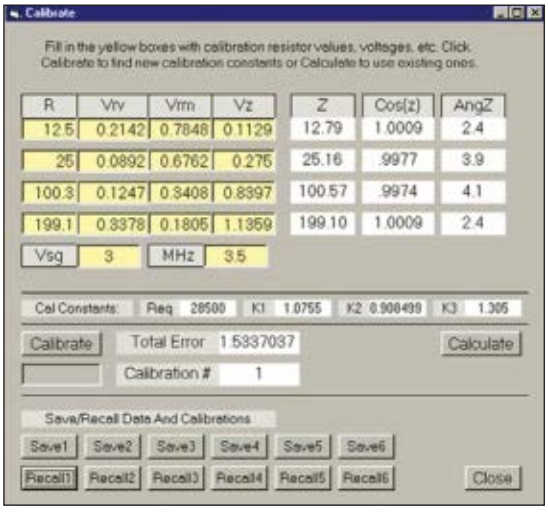
The impedance analyzer software is available on the *Nuts & Volts* website (**www.nutsvolts.com**). When you're ready, unzip the software to a new folder and run the executable (exe) program. It was tested with Windows 98 and XP. When you run the software, you may get a message like "Required DLL file MSVBVM60.DLL was not found." This is a Visual Basic run time file and is on many systems. If not found, you will need to obtain it and install it on your system. It is freely available from Microsoft and other sites on the web. It is usually available as Visual Basic 6.0 SP5: Run-Time Redistribution Pack (VBRun60sp5.exe) and is a self-extracting file. Download takes about six minutes at 28.8 kbps.

If you get the message "Component 'COMDLG32.OCX' or one of its dependencies is not correctly registered: a file is missing or invalid." when you try to run the program, you will need to register it on your system. It is also freely available from Microsoft and other sites on the web. More details are included with the software.

If you just want to experiment with the impedance analyzer program, go ahead as it does not modify the registry or install any other material on your computer. You can remove it by just deleting the entire folder it is located in.

A screenshot of the main screen of the impedance analyzer is shown in Figure 8. It is easy to use. Just enter the measuring frequency and the three voltage measurements you obtained from the circuit into a single row. Up to eight rows of data may be entered so that you can get a better picture of how the impedance varies with frequency.

To see the result for a row, click the "calculate" button in that row. That button also cycles through the Ls, Cs, and Cp options so you can view the results for different circuit models as discussed previously. The Lp model was not implemented as it is seldom used. You can also click the "calculate all" button at the bottom of the screen, if you wish to calculate all of the rows of entered data at one time. To get maximum benefits from the program, it should be calibrated as discussed next.



■ FIGURE 9. Calibration window of the RF impedance analyzer program.

Calibrating and Using the Impedance Analyzer

The parameters the program will use when the "calculate" button is clicked are displayed near the bottom of the main screen. These values correspond to Rm and the diode models used in the circuit. Parameters need to be changed since, when you obtain the program, they will correspond to the Rm and diodes in my circuit.

To get the proper values for your diodes is easy, and a calibration method using four resistors is part of the program. I have found that good results are obtained if you use two resistors above 50 ohms and two below 50 ohms. I use the values of 12.5, 25, 100, and 199 ohm (1/4 watt, 1% resistors) to get an SWR of about 4:1 above and below the 50 ohm nominal value. This gives maximum accuracy in this range of SWR. You don't need to use the same values as I did, but you do need to be able to measure them as accurately as possible for the program.

Now click "calibrate" at the top of the screen and a new window will open up as seen in Figure 9 with boxes for you to enter the resistor values and the corresponding measurements for each one. Let your equipment warm up for a few minutes before measuring and do it as accurately as possible. Include data on the measuring frequency and voltage level of the signal generator V_S so it can be saved with your measurement data. Then click the "calibrate" button and wait while the program calculates the best diode parameters for your application.

When finished, the right side of the screen shows the calculated impedance magnitude (which should be close to the resistor values) and the angles (which should be less than 6 degrees). When done, be sure to save the calibration using one of the buttons on the bottom. You may wish to provide other calibrations for different power levels or frequencies.

Up to six calibrations may be

saved. These can be called up from the main screen. Calibration data is saved in a file RFinit upon exit. My data is in the original file so you can see my resistor values, voltages, and calibration results. When you save your data, it will just overwrite the old data.

There is a quirk with the TVM calculation as alluded to earlier whereby the result of the cosine calculation may produce a value greater than one. This happens only with resistors where the phase angle is supposed to be zero. Slight inaccuracies in measurement are the cause of the problem. To keep you informed of this situation, the results of the cosine calculation are shown on the calibration screen. Don't be alarmed if you see cosines above one. Hopefully, they will be very close to one and won't affect the program results substantially. This is just a peculiarity of this method.

On the main screen, the box with the offending angle (cosine greater than one) will be highlighted in a red color. Since the error is often small and occurs mainly with resistors, the program will substitute a suitable small angle. In case you don't like the value chosen, you have the option of assuming the angle to be zero. Also, if you don't like the calibration values found by the computer algorithm, you can try to adjust them manually. The resulting error is shown on the screen as a guide. I have tried several times to "best" the program but have been unsuccessful. It seems to do a good job, though.

The calibrate algorithm is straightforward. An error criterion shown below is evaluated by a brute force search for the minimum of "Error." Each diode parameter is varied separately in tiny increments and "Error" calculated.

EQUATION 10

$$Error = \sum_{i=1}^{i=4} (Zmag(i) - Rcal(i))^2 + W(i)(\cos(i) - 1)^2$$

Here Zmag(i) is the calculated magnitude of Z, Rcal(i) is the calibration resistor, W(i) is a weighting factor on the cosine error, and "i" is the first through fourth calibration resistor. The first term in the sum is the error due to magnitude error or the difference between the calculated Z and the calibration resistor. The second term is the error between the calculated cosine and the value of one, which it would be for a resistor. The weighting factor W(i) is set to 10,000 since the cosine changes are small and change slowly near one.

The algorithm stops when it can find no variation in the diode parameter that reduces "Error" any further. These parameters are shown on the screen. This doesn't necessarily mean the lowest error is found. There may be other local minima due to the nonlinear property of the diode and there is a possibility that the algorithm has gotten stuck on one of these. But as noted above, I haven't been able to find a better minimum in my testing.

Determining the Sign of the Impedance Angle

We saw previously from Equation 4 that the analyzer cannot determine the sign of the impedance angle, θ, so let's explore other methods of finding it.

For lumped parameter components like capacitors and inductors, the sign is obvious since capacitive reactance is negative while inductive reactance is positive, as seen in Figure 1. This leads to the following simple rule of thumb for lumped parameter parts.

If $|Z|$ increases with increasing frequency, then the load is inductive and θ > 0. While if $|Z|$ decreases with increasing frequency, then the load is capacitive and θ < 0. So, by slightly changing the frequency and looking at the change of impedance, we can find the sign. This rule works for RC and RL circuits and even simple RLC circuits. An easy way of doing this is to monitor Vz. For example, if Vz is decreasing as frequency increases, the load is capacitive.

If we look at the input impedance of a transmission line with a load attached, the above rule is not strictly obeyed. It may be obeyed at some frequencies but not at others. There is a special case where it is obeyed — that of a zero resistance load — an example of which will be discussed later on. But in general, the rule does not hold, particularly if the load is complex. So, if you are not sure of the nature of the load attached to the transmission line, do not use the above rule.

There are other ways of finding the sign. It is an easy matter to add a small amount of reactance in series with the input and observe the angle change. For example, if you added some capacitive reactance and the angle increases, then the input is capacitive and the angle is negative.

If you know the length and type of transmission line and the type of load (such as an antenna), you can make some good estimates of the sign. For example, if the load is an 80-meter dipole of known resonant frequency, you can expect the antenna to be capacitive just below resonance and inductive above resonance. Then using a program like AC6LA's Transmission Line Details (TLD), you can calculate an estimate of the input impedance which should help determine the sign. TLD is designed for Windows and easily found on the web [3]. Let's look at some other applications.

Applications of an Impedance Analyzer

Uses for an impedance analyzer abound. And if the accuracy requirements aren't extreme, this unit can produce good results. It can be used to check components like inductors and capacitors at their operating frequency, measure the input impedance of a matching network, and even measure the impedance of an antenna. Coaxial cable transmission lines — which often seem mysterious to many — can be investigated easily with this analyzer.

First, let's consider a simple RC circuit consisting of a 100.3 ohm resistor and a 527 pF mica capacitor connected in parallel. The component values were individually measured at an audio frequency of 1 kHz. I connected them in parallel as the unknown Z for the analyzer, read the three voltages at 3.5 MHz, 7.0 MHz, and 10 MHz, and entered the data into the program. Figure 10 shows a comparison of the measured and theoretical values.

IMPEDANCE MEASUREMENT OF PARALLEL RC CIRCUIT

Frequency	Theoretical Z∠θ	R + jX	D	SWR	Rp	Cp
3.5 MHz	64.9 -49.2	42.6 -j49.5	0.86	2.8	100.3	527 pF
7.0 MHz	39.6 -66.8	15.6 -j36.4	0.43	5.0	100.3	527 pF
10.0 MHz	28.9 -73.2	8.4 -j27.6	0.30	7.9	100.3	527 pF

Frequency	Measured Z∠θ	R + jX	D	SWR	Rp	Cp
3.5 MHz	64.9 -49.1	42.5 -j49.1	0.87	2.8	99.1	529 pF
7.0 MHz	38.5 -65.4	15.9 -j35.0	0.46	4.7	92.5	537 pF
10.0 MHz	27.3 -70.9	8.9 -j25.7	0.35	7.1	83.3	551 pF

■ FIGURE 10. RC circuit test results compared to theoretical values.

Frequency	Comm. Analyzer	TVM Analyzer
6.6 MHz	79.1∠-21.9	76.9∠-26.9
6.7 MHz	73.9∠-13.2	73.1∠-16.5
6.8 MHz	69.7∠+0.6	72.6∠-7.7
6.9 MHz	73.9∠+14.2	74.6∠+11.1
7.0 MHz	80.0∠+23.2	83.9∠+17.7
7.1 MHz	88.9∠+31.9	93.0∠+27.4

■ FIGURE 11. Impedance of 40 meter long wire antenna.

Notice that at 3.5 MHz, the accuracy is very good although the SWR is over 2:1. As the frequency increases, and the SWR does too in this case, we see an increasing difference between the measured and theoretical values of the angle and magnitude. This translates to different values for the computed Rp and Cp components.

The increasing difference as the frequency climbs is probably due to several factors, including stray capacitance of the breadboard, long leads on the components, dissipation in the capacitor, diode modeling errors, and high SWR, in the last case, of over 7:1. This example should give you an idea of what to watch out for and what you can expect.

For the next example, consider measuring the impedance of a long wire antenna. To create the antenna, a spool of wire was unwound and strung out over the floor with a length of about 34 feet. This is close to one-quarter wavelength for the 40 meter ham band and should resonate near 7.0 MHz. One end of the wire was connected to the analyzer and the remainder, on the far end, left on the spool. While carefully tuning the signal generator frequency, V_{RV} was monitored with the DVM until a dip was found. This occurred near 6.8 MHz.

The antenna is expected to be capacitive below this frequency and inductive above it. Impedance measurements were then made at frequencies from 6.6 to 7.1 MHz. Figure 11 shows the results of the measurements along with those taken with a commercial RF impedance meter. The TVM analyzer data is shifted slightly in frequency, probably due to a small amount of stray capacitance. Otherwise, the TVM RF analyzer does a respectable job compared to the commercial unit.

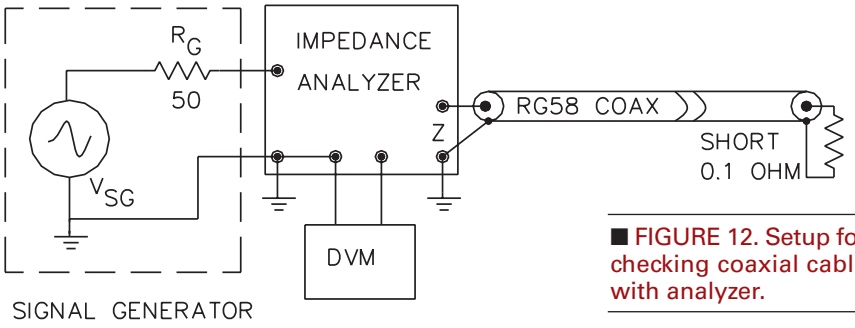
As a more complex example, consider a long piece of RG58 coax of unknown length that was pulled out of my junk box. We know that if the cable is 1/2 wavelength long, it will reflect the load impedance back to the input. So, initially we need to find the frequency corresponding to this length. This is easily done with the analyzer.

We start by making the load impedance of the coax a short circuit. This will reflect a small, nearly zero impedance back to the input at the 1/2 wavelength frequency. To find this point, we connect the analyzer to the input and vary the frequency while monitoring Vz for the lowest voltage. In my case, this occurred at 13.9 MHz. See Figure 12 for the test setup.

Next, I wanted to find the physical length and the input impedance of the cable at other frequencies. A coaxial cable with a short on one end presents a wide variety of input impedances that go from nearly pure capacitive to resistive to inductive and back to capacitive again, repeating the cycle over and over with frequency. As such, it makes an ideal test subject. But be warned, the impedances can extend into the thousands of ohms at some frequencies — well beyond the range of the analyzer.

Fortunately, there are programs available on the Internet to find the length and calculate the theoretical impedance given the 1/2 wavelength frequency. A good choice is the previously mentioned TLD. Given the load impedance (shorted in this case), it will calculate the theoretical length and input impedance of the cable at other frequencies. These values can then be compared to the values obtained by the analyzer and give us an idea of how well the analyzer performs. By the way, for a loss-less cable with a resistive termination (including a short), the above rule of thumb for finding the sign does hold. This is easily seen using TLD.

The cable manufacturer wasn't known, so Beldin was assumed. The cable data (RG58 Beldin 9201) and 1/2 wavelength frequency were entered into TLD and the physical length calculated as 23.35 feet. The load (short resistance) was assumed to be 0.1 ohms with zero reactance. Next, a number of frequencies were entered into TLD and the theoretical input impedances predicted.



■ FIGURE 12. Setup for checking coaxial cable with analyzer.

	TLD Calculated		TVM Analyzer	
Frequency	R + jX	|Z|	R + jX	|Z|
5.0 MHz	6.8 + j110	110	6.8 + j115	115
6.0 MHz	29.4 + j234	237	30.2 + j240	242
8.0 MHz	27.7 – j211	213	38.5 – j213	217
10.0 MHz	4.3 – j63	63	8.9 – j63	64
12.0 MHz	2.3 – j23.9	24	5.5 – j23.5	24
14.0 MHz	2.1 + j1.2	2.3	3.3 + j1.7	3.5
16.0 MHz	2.8 + j26.7	27	4.6 + j28.1	28
18.0 MHz	6.4 + j68.8	69	6.1 + j67.9	68
20.0 MHz	63.0 + j251	259	52.0 + j216	222

■ FIGURE 13. Coaxial cable test results of shorted cable.

This data along with selected, actual measured values obtained with the analyzer are shown in Figure 13.

As shown, the values are reasonably close. Don't assume all of the differences are due to errors of measurement of the analyzer. The theoretical calculations don't take into account connectors, the effect of splices (my cable had one), and age factors of the cable. In this case, I appreciate the confirmation of the closeness of the data but tend to lean to the actual measurements as being more true.

As an interesting experiment, if you connect an antenna to the coax as a load (replacing the short), you can again measure the input impedance at some frequencies of interest. Using TLD (in reverse), should then enable you to find the impedance at the antenna. This obviates the need to go directly to the antenna for measurement.

Final Comments

The straightforwardness of the impedance analyzer makes it attractive as a low cost measuring tool. But, belying this simplicity, there are limitations on its accuracy at low impedance angles and at high SWR. It certainly won't replace a good network analyzer, so don't sell your stock in Agilent!

On the other hand, it can be very useful in many situations where a more sophisticated instrument is not available. Accuracy is good over a reasonable impedance range of about 5 to 1,000 ohms, and better between 10 and 250 ohms. Angles near zero degrees (corresponding to a pure resistive load) and angles near 90 degrees (corresponding to a pure reactive load) are the least reliable. Making manual voltage measurements and entering them into a program may seem like a drawback to some, but I have found it to be surprisingly easy to do and very informative in many cases. I was often amazed by the analyzer's accuracy and seldom dissatisfied with it. Overall, it works well if you understand its limitations. If you find yourself making lots of measurements or needing more portability, you may want to consider moving on to a commercial impedance analyzer.

It was fun and instructive working with this impedance analyzer. I hope you will find that to be the case, too. So angle for some time, analyze your resources, and don't be impeded in building your own version! **NV**

Contact the Author

■ *George R. Steber Ph.D. can be contacted via email at steber@execpc.com with "TVM" in the subject line and email mode set to text.*

References

■ [1] George Steber, "A Low Cost Automatic Impedance Bridge" *QST*, October 2005, pp 36-39.

■ [2] George Steber, "LMS Impedance Bridge" *QEX*, Sep/Oct 2005, pp 41-47.

■ [3] Transmission Line Details, Dan Maguire AC6LA, available free as a download at **www.qsl.net/ac6la/tldetails.html**.

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BUILD A FOUR TRANSISTOR METAL DETECTOR

Want to be a treasure hunter? By discerning subtle changes in frequency, this design is capable of detecting coins to a depth of three to four inches.

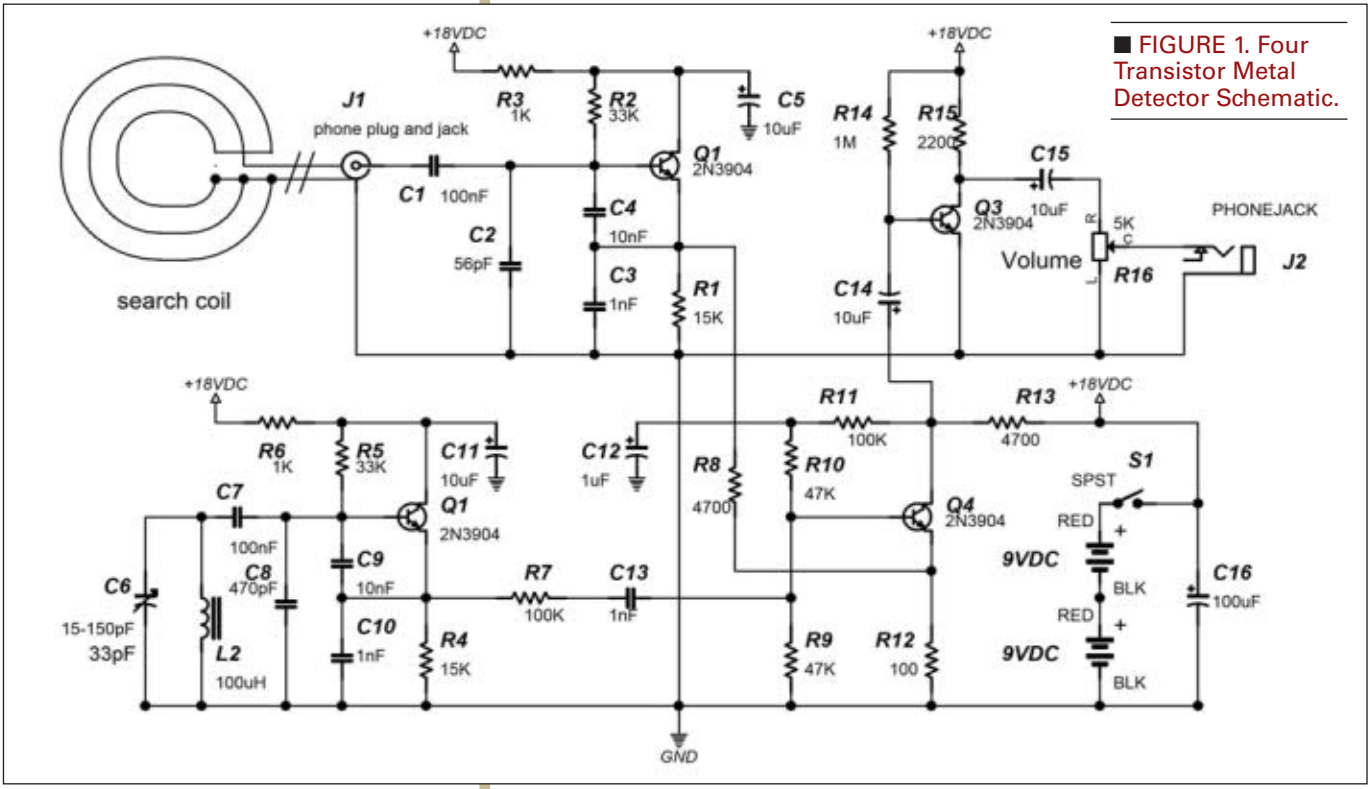
The circuit can sense a soda can at a depth of six inches and metal pipes at an even greater distance. The unit is powered by two 9V batteries in series. The detector has a current draw of approximately 9 mA at 18 VDC. As a result, the batteries should last a long time.

Theory

The design consists of four parts:

1) Q1 forms an oscillator whose frequency is determined by L1.
2) Q2 is a reference oscillator whose frequency is set by C6.
3) Q3 is a mixer that multiplies the outputs of Q1 and Q2.
4) Q4 is a simple one transistor amplifier.

L1 needs to be 100 µH. This inductor is created from 22 turns of 22 gauge magnet wire on a four



■ FIGURE 1. Four Transistor Metal Detector Schematic.

■ FIGURE 2. Search coil form.

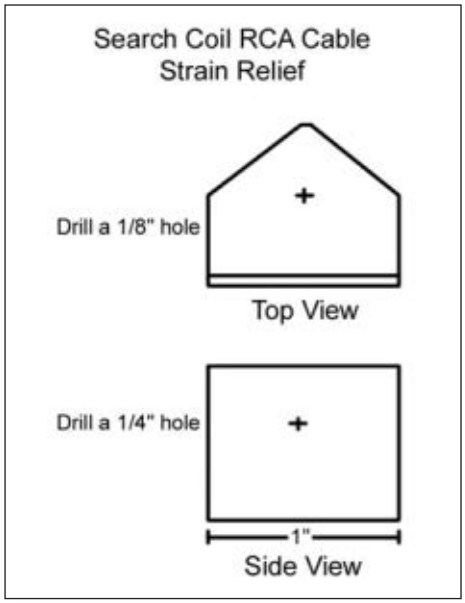
inch diameter coil form (see Reference 1). However, I wound the coil with 21 turns, resulting in an inductance of 88 µH. The inductance measured into the phono cable with the search coil connected is 126 µH. In order to work properly, you must use the audio cable specified in the Parts List. The resonant frequency is F = 1 / (2π*SQR(L1*C)). C= 1 nF in series with 10 nF + 56 pF. Solving yields C = 965 pF. Calculating for F gives 456 kHz. Therefore, the oscillation frequency of Q1 is 456 kHz when no metal object is near the coil L1.

The oscillator formed by Q2 is the reference oscillator. This frequency can be changed by adjusting C6. The output must be set within 2 kHz of Q1's output frequency. To obtain this result you may have to use a slightly different capacitor for C8. The part I used has a tolerance of ±20%. Note that the oscillation frequency of Q1 is very sensitive to stray capacitance.

The output of Q1 will vary about 70 Hz per each picofarad change of stray capacitance. Transistor Q4 forms a mixer. Q1 and Q2 both feed signals into this circuit. When a metallic object is close to the search coil, the inductance of L1 decreases. This causes Q1's oscillation frequency to increase. The output of the mixer is the sum and magnitude of the difference of the two signals: Fosc + Fref and |Fosc - Fref| (where "|x|" means "absolute value of x").

Suppose Fref = 500 kHz and Fosc = 501 kHz. The output of the mixer will be 1 kHz and 1,001 kHz. If Fref = 500 kHz and Fosc = 499 kHz, the output of Q4 is 1 kHz and 999 kHz. The frequencies output by the mixer feed a high input impedance BJT amplifier formed by Q3. The output of Q3 is capacitively coupled to the volume control R16.

The earphone used in this application must have a high impedance. The ceramic earphone specified in the Parts List has a 20 megohm impedance and works well. Note that both the high land low mixer frequencies are sent to the earphone. The earpiece shunts the higher frequency to ground, acting as a low-pass filter.



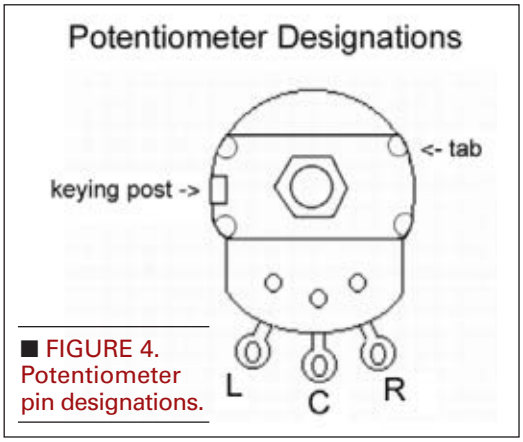
■ FIGURE 3. Search coil RCA cable strain relief.

Construction

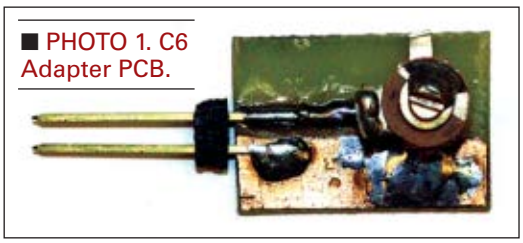
The circuit was built on a 2.6" x 3.5" piece of perfboard cut from PC board specified in the Parts List. Make a copy of the schematic and cross off the components as they are installed. An adapter was used to mount C6 (refer to Photo 1). To construct the board, cut a 1/2" by 3/4" piece of double or single sided PCB material. Use a permanent marker to mask the areas where the traces should go. Then, etch the board and clean the ink off with rubbing alcohol. Finally, solder the capacitor and SIP pins to the PCB in surface-mount fashion.

This adapter plugs into a two position SIP socket on the PCB. The

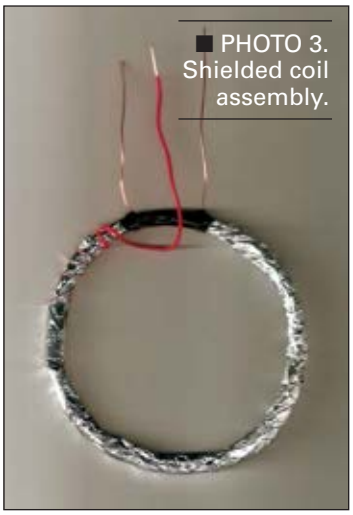
■ PHOTO 2. Coil assembly.



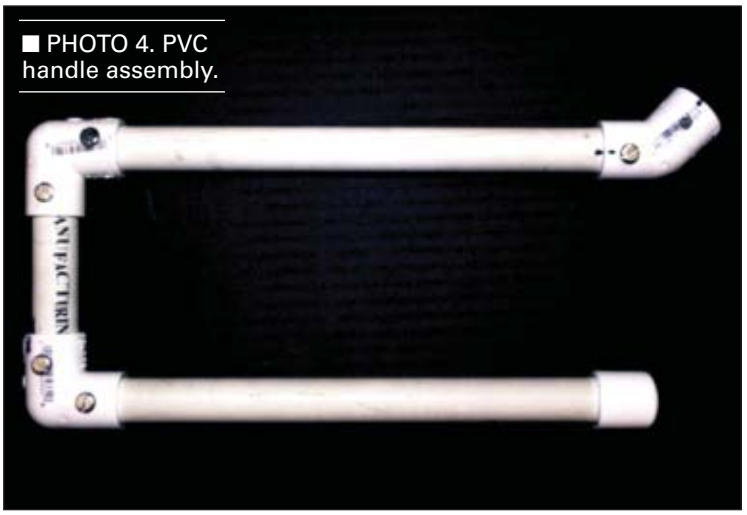
■ FIGURE 4. Potentiometer pin designations.



■ PHOTO 1. C6 Adapter PCB.



■ PHOTO 3. Shielded coil assembly.



■ PHOTO 4. PVC handle assembly.

Source (Crimp Housing)	# of Pins	Destination	Wire Type
COIL (L1)	2	J1 RCA Jack	Shielded Cable
VOL	3	R16	Twisted Trio
EAR	2	Phone Jack	Twisted Pair
S1	2	SPST Switch	Twisted Pair
18 VDC	2	9V Battery Snaps in Series	Battery Leads

■ TABLE 1

■ PHOTO 5. Search coil assembly with bracket.

pins of the adapter can be bent to 90 degrees for top adjustment. The volume control (R16) pin designations are shown in Figure 4. Break off the keying post of R16 with a pair of pliers. Instead of soldering the connecting wires directly to the PCB, .100″ male headers are used. These headers are installed for the search coil, volume, S1, earphone, and 18 VDC. Female crimp housing connectors are used to make the twisted pair cable assemblies shown in Table 1.

Be sure to note the ground pin on the COIL, VOL, EAR, and 18 VDC connectors. An easy way to do this is to make the ground connections with a black wire in the cable assemblies. Keep the cable to the RCA jack as short as possible to reduce stray capacitance.

To construct the search coil, obtain a 1X copy of Figure 2 (Search Coil Form). Use the template to cut a form from the wood slat given in the Parts List. Drill the six holes 5/32″ in diameter.

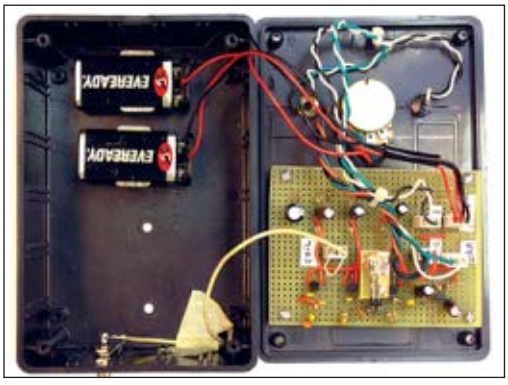
Now construct the wire coil. Wrap 21 turns of 22 gauge solid magnet wire around a 4″ diameter tube (an oatmeal container works nicely). Once the coil is wound, wrap it in electrical tape (see Photo 2). Wrap 1″ strips of aluminum foil around the coil, leaving space for the two magnet wire leads. Strip three inches of insulation from a six inch red 22 gauge solid wire. Wrap the three inch bare end of this wire around the aluminum foil (see Photo 3). Wrap the whole coil assembly with electrical tape.

Make the search coil strain relief bracket from a piece of aluminum sheet (Figure 3). A 1/4″ grommet is installed in the 1/4″ hole. Cut off one end of the RCA cable and feed it through the grommet. Remove 1″ of insulation from the end of the RCA cable. Cut the red wire from the search coil to 1/2″ long and strip the insulation to 1/4″. Scrape the enamel from the magnet wires with a razor knife and tin with solder.

Solder the magnet wire adjacent to the red wire along with the red wire to the shield connection of the RCA cable. The other magnet wire is soldered to the center conductor of the RCA cable. The solder connections should be less than 1/2″ and carefully wrapped with electrical tape or the output of the mixer may drift.

Next, mount the strain

■ PHOTO 6. View of open case.



■ PHOTO 7. Front panel view.

relief bracket to the wood slat with a 1/2″ 6-32 machine screw, two external tooth lock washers, and a 6-32 nylon lock nut. The coil is mounted to the coil form with three wire ties. Finally, attach the 45 degree 7/8″ inside diameter PVC elbow fitting to the coil form with two #6 x 1/2″ sheet metal screws. You must first drill 3/32″ pilot holes in the PVC joint to receive the screws. This 45 degree fitting receives one end of the metal detector shaft (a 33″ long piece of PVC tubing).

A photo of the completed search coil assembly with the bracket is shown in Photo 5.

Two 10″ and one 3.5″ lengths of 7/8″ diameter PVC pipe are used when making the handle for the metal detector. Refer to Photo 4 for assembly. The handle uses two 90 degree elbows and one 45 degree elbow. Two 5/32″ pilot holes and #10 1/2″ sheet metal screws are used when connecting each of these elbow joints to the PVC pipes.

Drill two 5/32″ holes in the bottom of the case as shown in Photo 6. These holes are used to attach the enclosure to the handle assembly.

Use Photo 7 as a reference when mounting the following items to the front panel: J2, S1, and R16. Drill appropriately sized holes in the lid for these items. Next, drill a hole for J1 next to the 45 degree elbow joint where the 33″ PVC pipe shaft attaches to the handle. Separate the lower and upper 10″ lengths of PVC pipe. Drill mounting holes in the lower 10″ piece of PVC pipe to match the holes in the bottom of the case drilled earlier and mount it with two 1-1/4″ 8-32 machine screws, external lock washers, and nuts.

Install J2, S1, and R16 on the housing lid. Attach J1 to the case. Screw the PCB to the front panel with four nylon 4-40 1/2″ threaded spacers and eight 4-40 screws. Connect the previously mentioned crimp housing cables between their sources and destinations. Attach the two 9V battery holders to the bottom of the case with double-sided adhesive tape.

Now, reassemble the upper and lower 10″ PVC pipe sections. Insert the 33″ main shaft into the handle assembly's 45 degree elbow joint, drill a pilot hole, and secure with a #10 1/2″ screw. The cap at the end of the handle is press-fit. Similarly, the search coil assembly is press-fit to the end of the 33″ metal detector shaft.

■ PHOTO 8. Completed metal detector.

Use

Once the PC board, search coil, housing, and handle assemblies have been made, follow these steps:

1) Plug the RCA cable from the search coil bracket to the metal detector

PARTS LIST

ITEM	DESCRIPTION	PART #	SUPPLIER
❑ R1,R4	15K 5% 1/4W		Various
❑ R2,R5	33K 5% 1/4W		Various
❑ R3,R6	1K 5% 1/4W		Various
❑ R7,R11	100K 5% 1/4W		Various
❑ R8,R13	4.7K 5% 1/4W		Various
❑ R9,R10	47K 5% 1/4W		Various
❑ R12	100 5% 1/W		Various
❑ R14	1M 5% 1/4W		Various
❑ R15	2.2K 5% 1/4W		
❑ R16	5K audio taper pot	255417	Jameco
❑ C1,C7	100 nF 50V ±10%		Various
❑ C4,C9	10 nF 50V ±10%		Various
❑ C3,C10,C13	1 nF 50V ±10%		Various
❑ C2	56 pF 100V ±20%		Various
❑ C8	470 pF 100V ±20%		Various
❑ C5,C11,C14-15	10 µF 50V ±20%		Various
❑ C12	1 µF 50V ±20%		Various
❑ C6	15-150 pF variable cap	94465	Jameco
❑ L1	See text		
❑ L2	100 µH ±5%	208194	Jameco
❑ Q1-Q4	2N3904 transistor		Various
❑ J1	RCA jack	159484	Jameco
❑ J2	3.5 mm phone jack	281834	Jameco
❑ S1	SPST switch	72160	Jameco
❑ Aluminum sheet	K&S Metals		Hobby Shop
❑ Wood slats	Forster 6-Count Slats		Craft Store
❑ PVC pipe	6' 7/8″ OD PVC Pipe		Hardware Store
❑ Audio cable	6 ft cable	42-4367	RadioShack
❑ Case	6 x 4 x 2	270-1806	RadioShack
❑ Battery snap	9V snap (2)	123-5118-GR	Mouser
❑ Earpiece	Ceramic earphone	25CR035	Mouser
❑ PCB	Prototype board	854-POW3U	Mouser
❑ Battery holder	9V holder (2)	534-071	Mouser
❑ Tape	Two-sided adhesive tape		Various
❑ Batteries	2 x 9 VDC		Various

housing RCA jack. Wrap the excess cable in spiral fashion along the length of the metal detector's shaft and secure with electrical tape. This will keep the cable from moving and causing a subsequent change in stray capacitance.

2) Plug the ceramic earphone into J2.

3) Turn the volume control completely clockwise.

4) Attach the two 9V batteries to the battery snaps and install the batteries into the holders.

5) Verify that S1 is in the On position.

You should hear a tone from the earpiece. The pitch at the earphone should increase when the search coil approaches a metal object. To obtain this result, make sure that no metal object is near the search coil and then turn C6 clockwise so that the pitch is a high tone, followed by a decreasing tone until the earphone is silent. Next, rotate C6 counter-clockwise until a frequency of approximately 2 kHz is reached. As mentioned before, if you are unable to tune the unit as specified, try reducing the value of C8.

Now that the tone has been set, attach the lid to the case with the four screws provided. If the metal detector does not balance properly, you may want to decrease the main shaft length to less than 33". Photo 8 shows the finished metal detector.

After the unit has been tested and completely assembled, it's time to look for coins and jewelry! Good places to find coins at shallow depths are under the swings at a playground and below bleachers. For very large metal objects at close distances, the output pitch of the metal detector may be higher than physically audible. Happy hunting with your four transistor metal detector! **NV**

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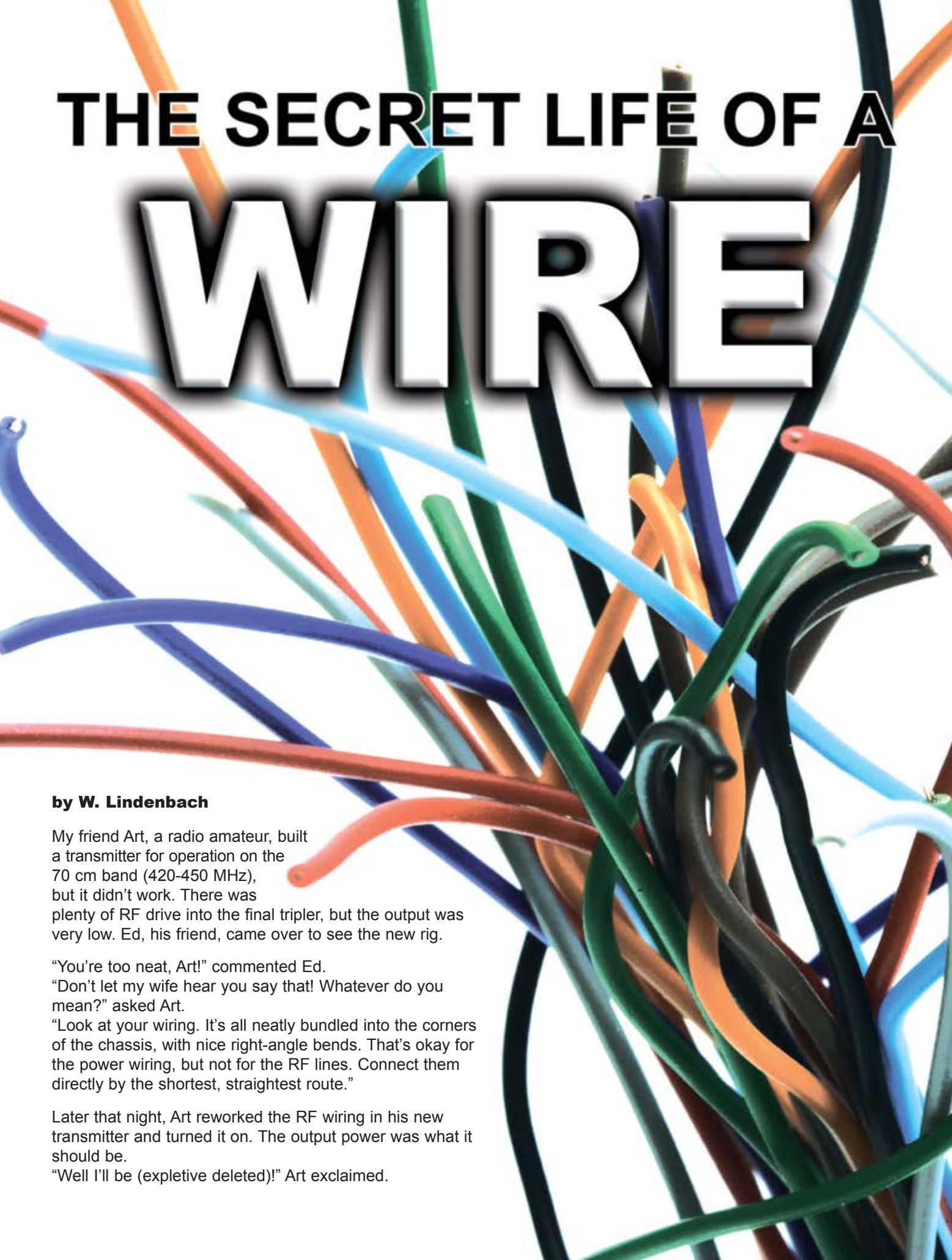
THE SECRET LIFE OF A WIRE



by W. Lindenbach

My friend Art, a radio amateur, built a transmitter for operation on the 70 cm band (420-450 MHz), but it didn't work. There was plenty of RF drive into the final tripler, but the output was very low. Ed, his friend, came over to see the new rig.

"You're too neat, Art!" commented Ed.
"Don't let my wife hear you say that! Whatever do you mean?" asked Art.
"Look at your wiring. It's all neatly bundled into the corners of the chassis, with nice right-angle bends. That's okay for the power wiring, but not for the RF lines. Connect them directly by the shortest, straightest route."

Later that night, Art reworked the RF wiring in his new transmitter and turned it on. The output power was what it should be.
"Well I'll be (expletive deleted)!" Art exclaimed.

Why did right-angle bends in the wires cause such a problem? As explained in this article, wires used in resistors, capacitors, inductors, antennas, and ground connections affect AC and DC signals differently.

ELECTRICAL PROPERTIES OF WIRE

A perfect wire should conduct a signal without adding noise, attenuation, or distortion. Whatever is electrically happening at one end of the wire should be happening at the other end exactly in the same form, no matter what the current, voltage, frequency, surroundings, or temperature. However, this isn't the case. For example, the effect of the wire on a signal depends on the frequency of the current that the wire is conducting. The higher the frequency, the more the effect of the wire on the signal.

When the current is DC (f = 0, that is, the frequency is 0 Hz), the behavior of the wire is most nearly the perfect behavior described above. The shape does not matter, what is near or around the wire does not matter, and the current flows in the whole wire. But the temperature matters. For example, six feet of No. 12 wire at room temperature (20°C) has a resistance of about 9.5 mΩ (0.0095Ω). At 30°C (hot day), the same wire has a resistance of 9.87 mΩ.

When the current is AC (at any frequency), new things begin to appear (the numbers in this next section are summarized in Table 1).

• *Resistance* — With AC, there are two kinds of resistance. The first is the ordinary well-known stuff that turns electric power into heat. The second is radiation resistance which turns alternating current into electromagnetic waves. That means that a wire becomes an antenna, which is certainly not an ideal conductor.

• *Skin Effect* — As the frequency increases, current moves out from the center of the wire, and concentrates at the surface so that, at high frequencies, all the current flows in a thin "skin" at the surface of the wire. To an RF (Radio Frequency) current, a wire looks like a thin tube or pipe.

RF currents could be considered "anti-social;" each RF current element tries to get as far away from every other element as possible. Since the current flows entirely on the surface of the wire, the inside of the wire might as well not be there. At 30 MHz, the effective conducting thickness of a copper wire is a surface skin about 0.5 mils (0.0005 inch) thick. So, a tube of copper half a mil thick and 80.8 mils in diameter is just as good at 30 MHz as a solid No. 12 wire.

Now the result of this skin effect anti-social behavior is that six feet of No. 12 copper wire has a resistance at 30 MHz of 400 mΩ, compared to 9.5 mΩ at DC. Even if the wire connects to a perfect ground at one end, the other end is not a good ground. And there will be about 2.2 µH of inductance, as well.

• *Proximity Effect* — If more surface area decreases the resistance, it would be reasonable to use more than one wire. Consider the result with three twisted No. 12 conductors six feet long. It would seem that the resistance should be one-third of that produced with one No. 12 conductor (0.4Ω). Instead, the RF resistance is now at least 0.18Ω (instead of one-third of 0.4Ω or 0.133Ω)! It could be a lot more; it depends very much on the condition of the wire surface. The inductance with this arrangement will be higher, too.

The proximity effect is very similar to the skin effect in that it can also be visualized as an anti-social tendency. The RF current will stay on the top surface of the wire so, with twisted wires, the current flows from one conductor to another, and that is a high-resistance path. Incidentally, this is why copper braid has a high RF resistance — up to 1Ω per foot at 20 MHz.

To avoid the proximity effect with twisted wires, use one wire of approximately the same size in circular mils as twisted wires. No. 6 wire has more than three times the cross-sectional area of No. 12 wire. Six feet of No. 6 wire will produce 0.2Ω of RF resistance (only half of the resistance of one No. 12 wire), and about 2.0 µH of inductance at 30 MHz.

Now consider the proximity effect in a coil. RF resistance is lower if the space between turns is equal to twice the wire diameter. Then, the RF resistance increases by only about 5%, whereas if the turns are tightly pressed against each other, the resistance increases by about 33%, avoiding the wire surface that is pressed against another wire surface. This is true if the current is flowing in the same direction in the closely spaced wires; if the current in adjacent turns were somehow flowing in opposite directions, the resistance increase would be much greater.

Conductor Type and Length at 20°C	DC Resistance	Resistance at 30 MHz	Inductance in Microhenries	Inductive Reactance at 30 MHz
No. 12 Copper, six feet long	0.0095 ohms	0.40 ohms	2.72 µH	513 ohms
Three Conductors of No. 12 Copper, six feet long	0.00318 ohms	0.18 ohms	(depends on wire surface condition)	(depends on inductance)
No. 6 Copper, six feet long	0.00237 ohms	0.20 ohms	2.0 µH	377 ohms
No. 30 Copper, six feet long	0.619 ohms	3.4 ohms	3.48 µH	656 ohms
Copper Foil, six feet long, one inch wide, five mils thick	0.0095 ohms	0.11 ohms	2.0 µH	377 ohms
Copper Foil, six feet long, two inches wide, five mils thick	0.00475 ohms	0.06 ohms	1.75 µH	330 ohms

TABLE 1. Resistance, Inductance, and Reactance.

• *Lazy Effect* — The numbers shown in Table 1 apply to straight wires. If they are curved or wound into a coil, the resistance rises because the RF current takes the shortest route, which is the side of the wire nearest the center of the coil. Taking only the inner surface of the wire around the coil reduces the amount of copper for conduction.

• *Reactance and Impedance* — These are forms of opposition only to the flow of AC current because they are dependent upon the frequency (see the sidebar *Calculating Reactance and Impedance*). Inductive reactance increases and capacitive reactance decreases as frequency rises. Impedance is a combination of resistance and reactance.

KINDS OF OPPOSITION

Making electronic circuits work correctly is a matter of making electrons go where they should and when. Controlling electron flow with "opposition" devices is a way to do that.

There are four kinds of opposition: resistance, inductive reactance, capacitive reactance, and impedance. Each is measured in ohms and Ohm's Law applies to all calculations with these effects. Here is a comparison of all four, and their respective behaviors:

COMPARISON OF RESISTANCE, REACTANCE, AND IMPEDANCE

TYPE OF OPPOSITION TO CURRENT FLOW	PRODUCED BY	MEASURED IN	RELATIONSHIP OF VOLTAGE AND CURRENT	BEHAVIOR WITH FREQUENCY
RESISTANCE	Resistors	Ohms	In phase	Same at all frequencies
INDUCTIVE REACTANCE	Inductors: Coils and Wires	Ohms	Current lags voltage by up to 90°	Increases linearly with frequency
CAPACITIVE REACTANCE	Capacitors: Any two conductors separated by an insulator.	Ohms	Current leads voltage by up to 90°	Decreases as the reciprocal of frequency
IMPEDANCE	Two, or all three of the above, in series or parallel combinations.	Ohms	Depends on proportions of reactance and resistance.	Can increase or decrease linearly or as the reciprocal of frequency.

WIRES AT RADIO FREQUENCIES

By reason of the skin effect, a solid copper wire looks like a very thin tube of resistive material to RF current at 30 MHz. And, since there is inductance, we can think of the wire not as straight but as a coil. See Table 1 for the characteristics of different sizes and shapes of wire at 30 MHz.

Now consider capacitance. A capacitor is formed wherever there are two conductors separated by an insulator. Think of two small spots on our thin-tube-of-resistive-material coil. There is air between these two surfaces which insulates them, and thus forms a capacitor! Well yes, but doesn't the conductor itself short these two surfaces together? Not quite. There is inductance and resistance between any two spots on the surface of our conductor. Now think of the whole surface of the conductor as separate spots, insulated from each other, and forming capacitors.

The net result for our 30 MHz RF current is a very thin tube of resistive material in the shape of a coil, bristling with capacitors all over the surface. If you are thinking of the inductance and capacitance in a single piece of wire producing a resonant circuit, you're absolutely right.

Considering the effects described above, at least three things can be done to minimize RF resistance:

(1) Make the surface area as great as possible. The thickness of the conductor is almost irrelevant.

(2) The conductor should be as nearly straight as possible. That means that "neat" wiring or circuit board layout (nice sharp bends) increases RF resistance.

(3) Conductors of RF currents should be kept apart, especially if the currents are flowing in opposite directions.

CIRCUIT BOARD TRACES

According to Table 1, the type of conductor with the lowest resistance and inductance is copper foil. Where is there a large surface of copper foil? Well, a copper-clad circuit board is most familiar. The copper forms what is called a ground plane — a very good term in this application.

Some circuit boards are copper-clad on both sides, with non-clad areas only where there are parts-mounting pads and connection traces. But, all of the copper foil that is not a connection trace is grounded. Circuit boards that have high-frequency signals or high-speed data — and therefore require very good grounds — are sometimes made with a copper foil surface on both sides with the connection traces on an internal layer. This arrangement illustrates the importance of a large surface area for a good ground, that is, very low resistance and inductance.

A double-copper-clad circuit board with conducting traces

FIGURE 1. Hewlett-Packard Type 8405A: Vector Voltmeter, Front Panel

CALCULATING REACTANCE AND IMPEDANCE

Here are "scalar value" equations for these quantities; there are "vector value" equations which are really neat, but they are not needed here.

Inductive reactance can be found with:

$X_L = 2\pi fL$ where: X_L is Inductive Reactance in Ohms.
π is Pi, a Greek letter which means "insert the number 3.1416"; it is the ratio of the circumference to the diameter of a circle.
f is the frequency in Hertz, or Cycles per Second.
L is Inductance in Henries.

Here is an example: if $f = 1MHz.$, and $L = 10\mu H$, $X_L = 62.8\Omega$

Capacitive reactance can be found with:

$X_C = \frac{1}{2\pi fC}$ where: X_C is Capacitive Reactance in Ohms.
π is 3.1416 (as above)
f is the frequency in Hertz, or Cycles per Second.
C is Capacitance in Farads.

Here is an example: if $f = 1MHz.$, and $C = 100pF$, $X_C = 1592\Omega$

Impedance can be found with:

$Z = \sqrt{R^2 + X^2}$ where: Z is Impedance in Ohms
R is Resistance in Ohms
X is Inductive Reactance, X_L, or X_C, Capacitive Reactance, in ohms.

Here is an example: if you connect a 10 ohm resistor and an inductor (whose reactance at a certain frequency is 10 ohms) in series, the result is $Z = 14.4\Omega$

* * *

between the two ground plane surfaces suffers from the proximity effect, capacitance to ground, and inductance in the traces. Circuit board traces have approximately 10 nH per centimeter of inductance (1,000 nH = 1 µH) and, with the capacitance of the ground plane, the traces can form a low-pass filter which will produce a falling frequency response, different time delays for different frequencies, and can produce ringing. As a result, data pulses will be rounded and timing may be wrong.

Circuit boards operating at frequencies greater than 1,000 MHz (this includes high-speed data) must use a different arrangement: a transmission line. Transmission lines have a characteristic impedance (Z_o) which is determined by the size and shape of the conductors and the thickness and type of material of the insulator between. A common transmission line is co-axial cable, such as RG-58, which has a characteristic impedance of 50Ω.

What is characteristic impedance? You do not measure it with an ohmmeter. If a transmission line, no matter how long, is terminated in its characteristic impedance, the other end will look like the characteristic impedance to RF currents. It will be a pure resistance if the termination is the correct, pure resistance. This is a very good arrangement because the inductance and capacitance no longer affect the frequency response.

INDUCTIVE CARROTS?

Inductive reactance and capacitive reactance are opposite: what one does, the other one does "upside down." Inductive reactance *increases* in direct proportion to the frequency; capacitive reactance *decreases* in inverse proportion to the frequency. And, they cancel each other. If you have equal quantities of inductive and capacitive reactance in series, you have nothing left but a little bit of resistance. This is called resonance.

In a resistance, the voltage and current are in phase. That is, when the voltage is at a positive peak, the current is also at a positive peak.

With pure inductive reactance, when the voltage is at a positive peak, *the current is at zero!* That means that the current *lags* the voltage by up to 90°.

In a pure capacitive reactance, when the current is at a positive peak, *the voltage is at zero!* That means that the current *leads* the voltage by up to 90°.

I found this a difficult concept, but there is an easy way to demonstrate it. Read the sidebar "Seeing Is Believing."

ANYTHING that behaves with the characteristics shown in the comparison table (see the "Kinds of Opposition" sidebar) is a resistor, inductor, or capacitor.

PRACTICAL APPLICATION

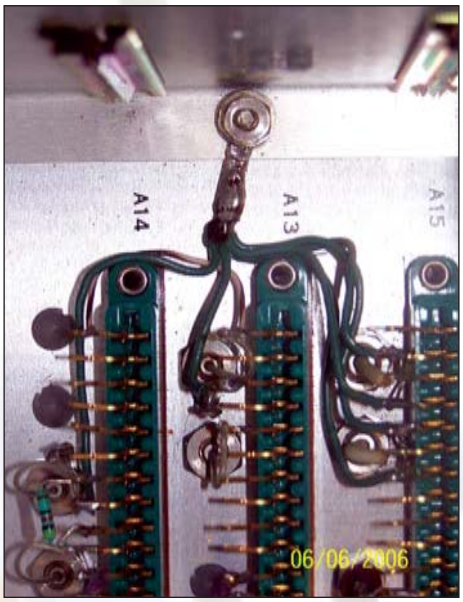
The most dramatic experience with wires that don't behave as wires that I have ever experienced happened about a year ago with an instrument called a vector voltmeter. Figure 1 shows the front panel. It's a wonderful old Hewlett-Packard instrument; it can tell you things about a circuit that a 'scope cannot. On my workbench, it is indispensable, and now it is irreplaceable since it is about 35 years old.

So, when it stopped working correctly, I had to fix it. It has an indicator on the front panel marked "APC unlocked" (Automatic Phase Control; similar to a phase-locked loop). When the APC is unlocked, the input signal (up to 1 GHz) and the internal phase-locked loop are out of synchronization. An internal phase comparator has to pull an internal oscillator to the correct frequency and phase, and keep it there even in the presence of frequency modulation. That's a very demanding operation!

It was getting harder and harder to lock the APC until, after a few weeks, it wouldn't lock at all. Without a perfect phase lock, the instrument is useless.

Signal sampling up to 1 GHz is accomplished with a 300 ps (3×10^{-10} second) pulse, adjusted to frequencies between 0.98 MHz and 2.0 MHz, producing a signal for measurement of 20 kHz. Such a short pulse contains energy at 3 GHz. The pulses are pro-

FIGURE 2. Hewlett-Packard Type 8405A: Vector Voltmeter Pulse Generator, showing modification for lower ground impedance (green wires) which restored the instrument to working condition.



duced on a circuit board in a shielded cage with sliding ground clips on the sides to contact the copper-clad circuit board. There were also ground wires on the edge connector. Producing a signal at such frequencies — and with such very precise and critical frequency and phase control — requires a very good ground. I suspected that the ground connections to the circuit board had somehow deteriorated over time.

Assuming 10 nh/cm (nanohenries per centimeter) of wire length, and four wires of about 2 cm length in parallel, the inductance would be about 5 nh and, at 3 GHz, the inductive reactance is about 90 ohms. What the reactance of the slide clips was, I couldn't possibly guess.

After making measurements, testing, viewing waveforms, replacing parts, making theological and biological comments in four letters, scratching my head and almost making a hole, somehow I decided to add some more ground wires to the pulse generator edge connector. They are the green wires in Figure 2. *It worked perfectly!*

I can only assume that, over the years, the circuit board grounding slide clips corroded, the ground impedance rose, which caused the APC to fail. The extra ground wires were each in parallel with the existing ground circuit, lowering the ground impedance and reducing interaction with other circuits. That's what can happen when a wire acts like an inductor and a resistor! **NV**

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(2) Dr. F. E. Terman, *Radio Engineer's Handbook*, First Edition: 1943, Section 2: "Circuit Elements," pp. 26-53. McGraw-Hill Book Company.

(3) Other books by Dr. Terman:

Electronic and Radio Engineering, 1955

Fundamentals of Radio, 1938

Electronic Measurements, 1952

If you can find these books anywhere, and can afford them, grab them; you'll never regret it.

These books are worth any couple dozen others that I can think of. Dr. Terman was a great teacher; perhaps the greatest electronics teacher ever. The Griffith text guided me through an AM broadcast transmitter installation. I cannot recommend these books too highly.

SEEING IS BELIEVING

You can see the current waveform leading the voltage waveform in a capacitive reactance with a simple setup:

(1) The parts required are a 0.1 µF capacitor and a 1.0 Ω resistor. The values can be approximate.

(2) Connect the capacitor and resistor in series.

(3) Connect a signal generator output to the capacitor free end and ground to the resistor free end. The generator should be able to provide about 1.5V RMS at 30 kHz into a 50 Ω load.

(4) Connect a dual-trace 'scope so that the generator output can be seen on Channel 1, and the voltage across the 1.0 Ω resistor on Channel 2.

(5) Adjust the scope's vertical sensitivity so that both traces cover the graticule vertically.

(6) Adjust the scope's horizontal sweep so that both traces show about one cycle and, with the generator output turned off, the traces are on the center horizontal line of the graticule. If there is DC in the generator output (the Channel 1 trace moves vertically as you adjust the generator output), switch the 'scope inputs to "AC coupling."

(7) You will see the Channel 2 trace is to the left (leading) of the Channel 1 trace by about one-quarter of a cycle, or about 90°.

The Channel 2 trace from the 1Ω resistor is showing the current waveform through the capacitor. The capacitive reactance of the capacitor at 30 kHz is about 50 ohms, so the 1Ω resistor, being so much smaller, does not change the phase relationship significantly.

If the capacitor were replaced by an inductor of about 265 µH (inductive reactance of about 50 ohms at 30 kHz), the Channel 2 trace (current) would be to the right (lagging) of the Channel 1 trace by about a quarter of a cycle.

This is a hard concept: voltage and current in phase in a resistance, current leading the voltage by 90° in a capacitance, and current lagging the voltage by 90° in an inductance. It is the convention to refer phase shift to the voltage waveform, that is, the voltage waveform is considered to be at 0°. Then, if the current is ahead of the voltage (leading), it is considered to be at a positive angle; if the current waveform is behind the voltage waveform (lagging) it is considered to be at a negative angle.

I have found it easier, in a series circuit, to think of the current waveform as a reference, and then to think of the voltage waveform as a result of the effect of the resistance or reactance (or combination) on the current. But then, before any calculations, it is necessary to readjust the observation to conform with the convention (voltage at 0°).

HDTV Audio

In the December '07 issue, we examined the various ways to hook up pieces of your home entertainment system to your HDTV. We specifically focused on the different video interfaces. We'll continue now with the choices for passing audio from one device to another.

by Jeff Mazur

Once again, the most common connection by far is the standard analog stereo pair using RCA jacks and cables. With good quality cable and connectors, this method can provide excellent results. The most common issue with analog audio connections is its susceptibility to picking up hum and/or other extraneous signals, especially from components within your system (or perhaps from the ham operator who lives next door!). To solve this issue — as well as complete the total conversion to binary 1s and 0s — there are three basic ways to pass audio signals digitally between devices: coax, optical, and HDMI.

Figures 2-4 are courtesy of Wikipedia, the free encyclopedia (licensed to the public under the GNU Free Documentation License).

FIGURE 1. Digital audio connections (top, coax and bottom, optical).

S/PDIF (Sony/Philips Digital Interconnect Format)

Named after the two companies that developed this interface, S/PDIF is a means to carry audio between devices in a digital format. The signals can be carried over standard 75 ohm coaxial cable using RCA jacks (or BNC connectors in professional equipment) or via optical fiber (glass or plastic, usually terminated with F05 connectors). See Figure 1.

The optical connection — created by Toshiba and also known as TOSLINK — uses 1 mm fiber terminated in a 5 mm connector. While earlier cables were restricted to less than 15 feet, you can now buy high quality TOSLINK cables up to 100 feet in length. TOSLINK can carry data signals of up to 125 Mbits/s, which allows for three audio channels. However, it is usually used to carry a single pair of stereo audio signals.

As an electrical signal, S/PDIF is represented by a roughly 1V digital pulse train using Biphase Mark Code (BMC) to carry the audio data. While no specific sampling rate or bit depth is specified in the standard, audio is usually carried as either 48 kHz (DAT) or 44.1 kHz (CD) data with either 20 or 24 bit samples. We'll describe the actual data format in a moment.

HDMI

We've already discussed the HDMI interface that can carry digital video between devices. HDMI also includes support for up to eight channels of uncompressed digital audio at a 192 kHz sample rate with a

24 bits/sample, as well as compressed streams such as Dolby Digital, or DTS. HDMI also supports one-bit audio, such as that used on Super Audio CDs at rates up to 11.3 MHz. With version 1.3, HDMI now also supports lossless compressed streams such as Dolby TrueHD and DTS-HD Master Audio.

Digital Audio Basic

Digital audio connections can be used to connect various components of your home entertainment system such as from a cable or satellite STB (Set Top Box) to the TV. Since audio is transmitted digitally in the ATSC DTV signal, this will often be the best choice. Other components (e.g., a CD player) also handle audio natively in a digital form. However, devices that handle audio as an analog signal — including the equipment used to record or create TV audio at its source — must first convert the analog signal to digital. This process is known as digitizing and is a good place to start when discussing digital audio.

To digitize an analog signal, we basically perform two separate functions. First, the signal is sampled at regular intervals to determine its value at each discrete point in time. This is usually the function of a sample-and-hold circuit. Next, each sample is quantized, or converted from an analog voltage to a particular digital representation of that value.

The sampling rate determines what frequencies can be carried digitally; information theory tells us that only frequencies below one-half of the sampling frequency (also referred to as the Nyquist frequency) can be represented accurately. Signals above this limit will cause extraneous frequencies (i.e., distortion) to appear due to an effect known as aliasing. In other words, we need at least two samples per cycle of the highest frequency we wish to digitize.

The quantization of each sample determines how many bits will be used to represent each sample. The more bits, the higher the precision will be of each sample. This translates into the dynamic range of a signal, or the difference between its lowest and highest values. Under ideal conditions, it also represents the maximum signal to noise ratio (SNR), which is related to the number of bits by the following formula:

$$SNR = 20 \log 2^N = \text{approx } (6 \times N) \text{ dB}$$

where N = number of bits.

For example, a 20-bit converter theoretically could obtain an SNR of 120 dB (if there are no other sources of noise). In practice, the maximum signal level is usually reduced by 20 dB of headroom to prevent clipping. This still leaves an SNR of approximately 100 dB. In comparison, normal audio tape typically only achieves an SNR of about 60 dB.

As you can see, digitizing an analog signal is all about compromise. You need to sample at a high enough rate so as not to miss changes in the signal that occur between the samples. And we need enough bits to represent each sample so that the difference between the actual analog value and its closest digital representation (a.k.a., quantization error) is not very much. Of course, increasing either of these values means that there will be more digital data that needs to be carried and processed.

On the positive side, once a signal has been digitized it can be transmitted much more efficiently and without many of the side effects of noise and distortion present in the communication channel used. More importantly, it can be compressed digitally so that redundant and/or unessential data can be discarded. This is one of the main reasons that our TV signals are undergoing the transition to digital.

PCM

There are many ways to represent each sample as a digital signal. The most common technique is known as Pulse-Code Modulation (PCM). This approach simply takes the output from an Analog-to-Digital Converter (ADC) and places the bits into a continuous bitstream.

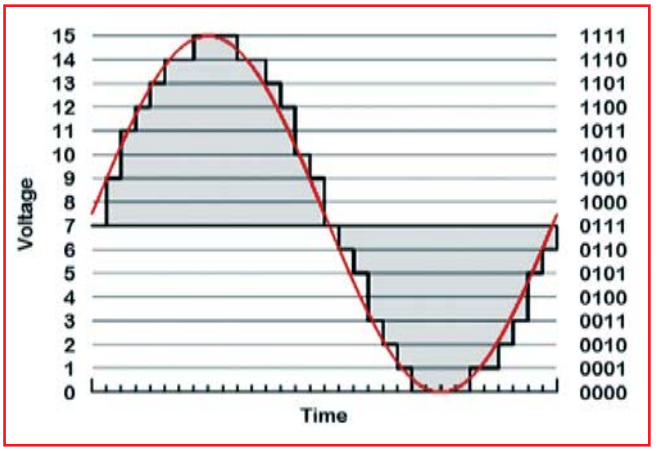

FIGURE 2. Analog-to-digital conversion of a signal using Pulse Code Modulation (PCM).

Figure 2 shows a sine wave (in red) that is sampled and quantized using simple PCM. At each sample point, the digital representation of the signal's analog value is sampled and then held until the next sample point. This produces an approximation of the original signal, which is easily encoded as digital data. For example, if the sine wave in Figure 2 is quantized into 16 values (i.e., four bits), we would generate the following data samples: 1001, 1011, 1100, 1101, 1110, 1110, 1111, 1111, 1111, 1110, etc.

We could transmit these PCM samples as four-bit parallel data with a separate clock signal to indicate when each sample was taken. This is cumbersome, however, and requires the use of multi-conductor cables. Most data transmission today is done in a serial fashion. This requires that each bit of the PCM sample be clocked out onto a single serial data line. At the receiving end of this data stream, a shift register will convert the serial data back into parallel data words. To keep the receiver in sync with the transmitter, some form of clock recovery is necessary.

One of the easiest ways to do this is to make sure that the serial data changes polarities at least once during each bit-time. This is the basis for several different coding schemes, including Biphase Mark Code (BMC) — the signaling method used by both TOSLINK and the professional digital audio format established by, and referred to as, AES/EBU (Audio Engineering Society

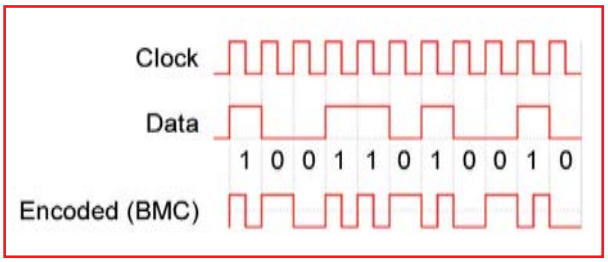

FIGURE 3. Serialization of digital data using Biphase Mark Coding (BMC).

and the European Broadcasting Union).

With BMC, the data stream changes value at the beginning of each data bit. A logic 1 is represented by having the stream change value again during the middle of its bit time; it does not change for a logic 0 (see Figure 3). BMC coding provides easy synchronization since there is at least one change in polarity for every bit. Also, the polarity of the actual signal is not important since information is conveyed by the number of transitions of the data signal.

Another advantage of BMC is that the average DC value of the data stream is zero, thus reducing the necessary transmitting power and minimizing the amount of electromagnetic noise produced by the transmission line. All these positive aspects are achieved at the expense of using a symbol rate that is double the actual data rate.

Transmission Protocol

S/PDIF and its professional cousin, AES/EBU, were designed primarily to support two channels of PCM encoded audio at 48 kHz (or possibly 44.1 kHz) with 20 bits per sample. Sixteen-bit data is handled by setting the unused bits to zero; 24-bit data can be achieved by using four auxiliary bits to expand the data samples. The low-level protocol used by both S/PDIF and AES/EBU is the same, with the exception of a single Channel Status bit.

To create a digital stream, we break the continuous audio data into smaller packets or blocks. Each block is further divided into 192 frames. Note, however, that these frames have nothing to do with frames of video. In fact, when digital audio is combined with digital video signals, there are a number of steps that must be taken to make them compatible. First off, both digitizing clocks must be synchronized to a common 27 MHz timebase. Even so, a frame of NTSC video has a duration of:

1 / 29.97 = 33.366... ms

At 48 kHz, an audio frame has a duration of:

1 / 48,000 = 20.833... µs

This makes a complete audio block 192 x 20.833 = 3,999.4 µs. The number of audio samples per video frame, however, is not an integer number:

33366 / 20.833 = 1601.6 audio samples/video frame

Because of this, it takes a total of five video frames before an even number of audio samples corresponds to an even number of video frames (8,008 audio samples per five video frames). Some video frames are given 1,602 samples while others are only given 1,601. This relationship is detailed in Figure 4.

Each audio frame consists of two subframes: one for each of the two discrete audio channels. Furthermore, as shown in Figure 4, each subframe contains 32 bits — 20 audio sample bits plus 12 extra bits of metadata.

There is a single Channel Status bit in each subframe, making 192 bits per channel in every audio block. This means that there are 192 / 8 = 24 bytes available in each block for higher level metadata. In S/PDIF, the first six bits are organized into a control code. The meaning of these bits is:

bit	if 0	if 1
0	Consumer	Professional
1	Normal	Compressed data
2	Copy Prohibit	Copy Permitted
3	Two Channels	Four Channels
4	—	—
5	No pre-emphasis	Pre-emphasis

In AES/EBU, the 24 bytes are used as follows:

- Byte 0: Basic control data — sample rate, compression, emphasis modes.
- Byte 1: Indicates if the audio stream is stereo, mono, or some other combination.
- Byte 2: Audio word length.
- Byte 3: Used only for multichannel applications.
- Byte 4: Suitability of the signal as a sampling rate reference.
- Byte 5: Reserved.
- Bytes 6–9 and 10–13: Two slots of four bytes each for transmitting ASCII characters.
- Bytes 14–17: Four-byte/32-bit sample address, incrementing every frame.
- Bytes 18–21: As above, but in time-of-day format (numbered from midnight).
- Byte 22: Contains information about the reliability of the audio block.
- Byte 23: CRC (Cyclic Redundancy Check) for error detection. The absence of this byte implies interruption of the data stream before the end of the audio block, which is therefore ignored.

AC-3

As previously mentioned, raw PCM data would require a large bandwidth to transmit. For surround sound, this would require approximately six channels x 48 samples/s x 20 bits = 5.7 Mb/s. With appropriate compression, however, this can be reduced to 384 Kb/s.

Dolby Digital — officially known as AC-3 (Adaptive Transform Coder 3) — is the compression scheme used to transmit audio within the ATSC DTV data stream. It can represent up to five full bandwidth (20 Hz-20 kHz) channels of surround sound (Right Front, Center, Left Front, Right Rear, and Left Rear), along with one low frequency channel (20 Hz–120 Hz) for subwoofer driven effects. This is often referred to as 5.1 surround sound.

A complete description of the

Figure 4

Bits 0 to 3

These do not actually carry any data but they facilitate clock recovery and subframe identification. They are not BMC encoded so they are unique in the data stream and they are easier to recognize, but they don't represent real bits. Their structure minimizes the DC component on the transmission line. Three preambles are possible:

X (or M): 11100010 if previous state was "0;" 00011101 if it was "1."

Y (or W): 11100100 if previous state was "0;" 00011011 if it was "1."

Z (or B): 11101000 if previous state was "0;" 00010111 if it was "1."

They are called X, Y, Z from the AES standard; M, W, B from the IEC 958 (an AES extension). The eight-bit preambles are transmitted in the same time allocated to four (BMC encoded) bits at the start of each sub-frame.

Bits 4 to 7

These bits can carry auxiliary information such as a low-quality auxiliary audio channel for producer talkback or studio-to-studio communication. Alternately, they can be used to enlarge the audio word length to 24 bits, although the devices at either end of the link must be able to use this non-standard format.

Bits 8 to 27

These bits carry the 20 bits of audio information starting with LSB and ending with MSB. If the source provides fewer than 20 bits, the unused LSBs will be set to a logical "0" (for example, for the 16-bit audio read from CDs, bits 8-11 are set to 0).

Bits 28 to 31

These bits carry associated status bits as follows:

- V (28) Validity bit: It is set to zero if the audio sample word data are correct and suitable for D/A conversion. Otherwise, the receiving equipment is instructed to mute its output during the presence of defective samples. It is used by players when they have problems reading a sample.

- U (29) User bit: Any kind of data such as running time, song, track number, etc. One bit per audio channel per frame form a serial data stream.

- C (30) Channel status bit: Its structure depends on whether AES/EBU or S/PDIF is used (see text).

- P (31) Parity bit: For error detection. A parity bit is provided to permit the detection of an odd number of errors resulting from malfunctions in the interface. If set, it indicates an even parity.

AC-3 standard and its use in ATSC transmission is quite complex and beyond the scope of this article. You can download the entire ATSC audio standards document (A/52B) using the link given under Further Info. However, there are however some interesting details worth mentioning here.

ATSC Audio Details

Unlike analog NTSC, audio does not take a backseat to video in ATSC. Quite a bit of the standard is devoted to how sound will be delivered to the viewer. We've already seen how 5.1 surround sound can be transmitted with each DTV channel. Other parameters in the audio metadata can be used to enhance the viewing experience. One of these parameters is known as dialnorm.

The purpose of dialnorm is to equalize the sound levels when changing from one program to another. The value of this parameter — which is embedded within the audio stream — is meant to indicate the level of average spoken dialog within the complete audio program. This is then used to control the decoder compres-

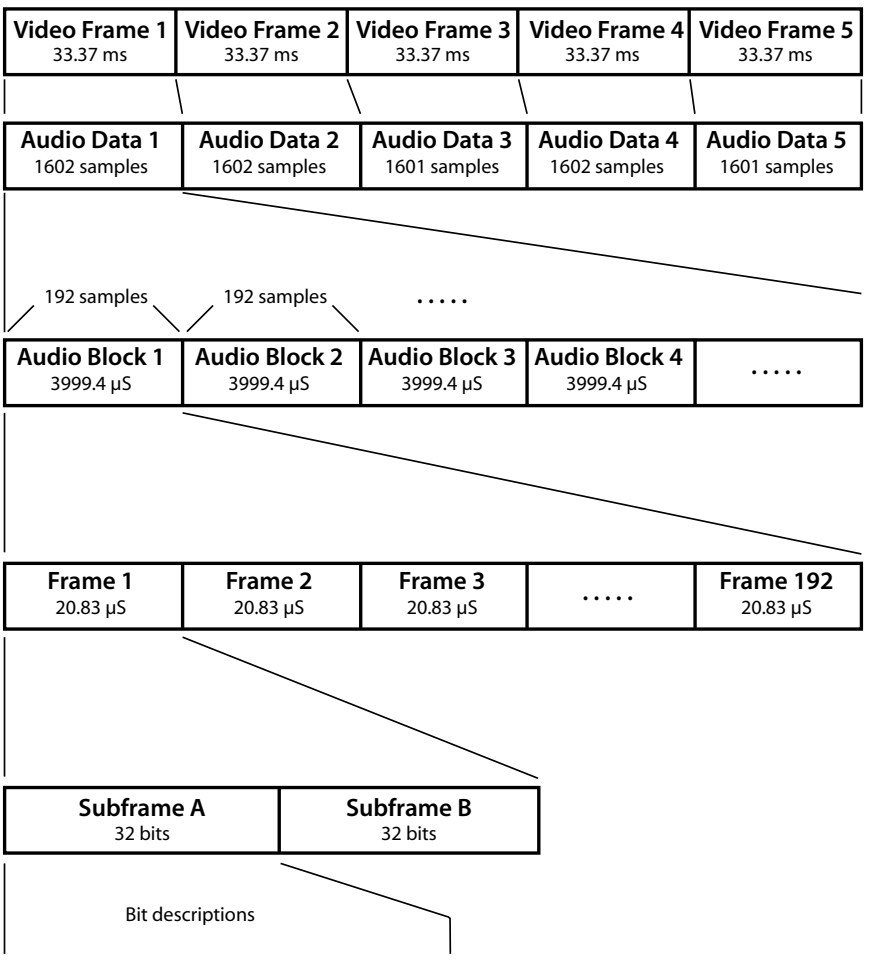

FIGURE 4. Packetization of data in digital audio streams.

sion gain within the HDTV receiver. If set properly, it will maintain a consistent dialog level between program elements and when changing from one channel to another, hence the abbreviation of "dialog normalization."

The dialnorm parameter ranges in integer values from 31 (where decoder gain remains at unity) to a value of one (where decoder gain is reduced by 30 dB). Unfortunately, many producers and broadcasters currently do not provide a proper dialnorm value in their programs. This is partly due to the complexity and variability of actually measuring the dialog level properly. Thus, you may still find wildly varying levels between channels.

Other Audio Services

The ATSC standard also provides for alternate audio channels by allowing multiple AC-3 elementary streams within the full transport stream. As such, each alternate audio channel can have up to 5.1 channels of its own to provide a complete audio service. It is also possible for the alternate audio to consist of a single channel intended to be combined with other channels from a different stream (although not all HDTVs are capable of this).

One obvious use for an alternate audio channel would be to convey the dialog in a different language, much like the SAP (Secondary Audio Programming) service, currently available on NTSC channels. Because there can be any number of audio streams, this would allow multiple languages to be transmitted at the same time.

The ATSC standard also identifies several types of audio signals that can be transmitted. These are specified in Table 5.7 of the A/52 document (see Table 1).

A complete main (CM) channel represents the main audio service with dialog, music, and effects. This is the normal audio program which can be monaural (one channel), stereo (two channel), or surround sound (5.1 channel) where available. A music and effects channel (ME) contains only those respective portions of the audio, without dialog. This would be useful when supplying a program in multiple languages; the single ME service would be combined with various other streams containing only a dialog (D) service for each language.

The visually impaired (VI) service is designed to allow a separate audio channel to contain a narrative description of the program content. Also known as video described, this aids a person who is blind or otherwise visually impaired to comprehend what is happening on the screen. Likewise, the hearing impaired (HI) service is provided to aid those with slight hearing loss. Unlike captioning, which can provide audio content for those who are completely deaf, the HI service is designed to provide more intelligible audio by processing (compressing) the dialog channel and emphasizing it over the music and effects.

While the dialog service contains actual program dialog from the speaking actors, an additional commentary (C) service can be added to provide further information. This is like many DVDs which offer a special audio track to provide director's or actor's comments while you watch their movie.

The emergency (E) service is a special, high priority channel which can be used to convey vital announcements similar to the Emergency Alert System (EAS). Whenever an E service signal is present, it will automatically mute and/or replace the normal audio channels with the E channel audio.

The voice over (VO) and karaoke services allow an additional channel to be added to an existing AC-3 stream without requiring the audio to be decoded (i.e., uncompressed) back to baseband PCM audio data, mixed, and then re-encoded. Local stations could use this to add their own audio tags to programming supplied by their network.

Lip Sync

Because audio and video are processed separately by various circuits which can delay the signals significantly, special attention is needed to keep these parts of a presentation in sync. When they drift apart past a certain threshold, the discrepancy becomes very noticeable and objectionable.

Technically called audio/video sync, this quality is often referred to as lip sync (not to be confused with a Milli Vanilli performance). A/V sync errors are becoming a significant problem in the digital television industry because of the use of large amounts of video signal processing in television production and broadcasting and fixed pixel, progressive television displays such as Plasma, LCD, and DLP sets.

Studies have shown that "When audio precedes video by five video fields (83 ms), viewers evaluate people on television more negatively (e.g., less interesting, more unpleasant, less influential, more agitated, less successful). Viewers can accurately tell when a television segment is in perfect sync, and when it is five fields out of sync." See the Reeves and Voelker reference in the sidebar.

Furthermore, there is a larger tolerance for audio that is delayed in comparison to the video. This is a phenomenon that we are all used to when we watch a fireworks display or, to a larger degree, an electrical storm. We see the effect before we hear it. Of course, this is due to a totally different reason: the difference in velocity between light and sound waves. But if you've ever had to watch a program with significant A/V

Table 1. Bit Stream Modes

bsmod	acmod	Type of Service
000	Any	Main audio service: Complete main (CM)
001	Any	Main audio service: Music and effects (ME)
010	Any	Associated service: Visually impaired (VI)
011	Any	Associated service: Hearing impaired (HI)
100	Any	Associated service: Dialog (D)
101	Any	Associated service: Commentary (C)
110	Any	Associated service: Emergency (E)
111	001	Associated service: Voice over (VO)
111	010 - 111	Main audio service: Karaoke

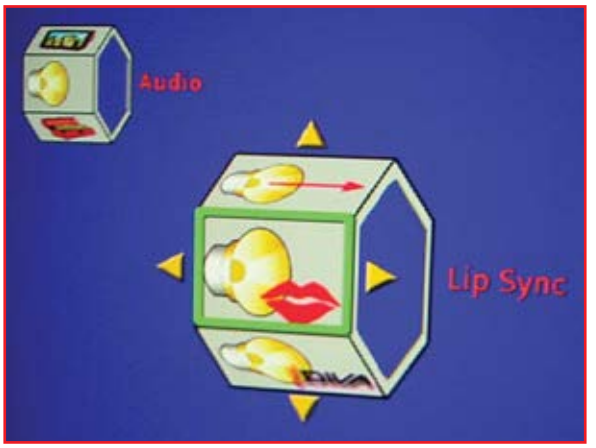

FIGURE 5. Lip sync adjustment on an HDTV.

sync error, you know how annoying it can be.

Good engineering practices specify that the audio should never lead the video by more than 15 milliseconds or lag by more than 45 milliseconds. To keep the audio and video signals in sync, Presentation Time Stamps (PTS) are added to the transport stream packets. This allows the MPEG decoder in the receiver to re-assemble the packets correctly and keep the audio and video (and captions, etc.) in sync.

When the audio and video packets are multiplexed together, they can be sent up to one second apart. Fortunately, most of the other delays in the transport stream affect audio and video together. However, if you consider the delays encountered in encoding, buffering, multiplexing, transmission, demultiplexing, decoder buffering, decoding, and presentation, there can be over five seconds of delay between the broadcast input and your TV display. You can easily see this by switching between one of your local station's analog and digital channels.

Even if the receiver in an HDTV decodes a perfectly synchronized signal, there still can be a difference in the picture and sound when viewed. This is because TVs now have lots of computing power and use it to enhance HD, as well as SD pictures. They have large video buffers and DSP (Digital Signal Processing) chips to perform resolution changes (mapping the incoming video resolution to the native resolution of the display device) and correction for progressive display of interlaced sources (de-interlacing and 3:2 pull-down removal). They can also perform image enhancement to reduce specific artifacts of the display (e.g., Sony's Digital Reality Creation).

Some of these processes add considerable delay, especially when they need to examine multiple video fields to perform their function. This can cause noticeable A/V sync errors. Some HDTVs now have user adjustments to compensate for this (see Figure 5). **NV**

Further Info

Digital Audio Compression Standard (AC-3, E-AC-3) Revision B
www.atsc.org/standards/a_52b.pdf

"Effects of Audio-Video Asynchrony on Viewer's Memory, Evaluation of Content and Detection Ability"
by Reeves and Voelker
www.lipfix.com/file/doc/reeves_and_voelker_paper.pdf

Glossary of Useful Terms

ATSC Advanced Television System Committee — The organization and name of the digital television standard adopted in the US.

DTV — Digital Television

DAT — Digital Audio Tape

HDMI: High-Definition Multimedia Interface — A method of connecting components using a single cable that carries digital video signals along with multichannel digital audio.

HDTV: High Definition TeleVision — Part of the new Digital Television standards, those formats that have either 720 or 1080 lines of vertical resolution.

MPEG :Motion Picture Experts Group — Standard for transmitting compressed audio and video.

NTSC: National Television System Committee — The organization and name of the analog television standard currently used in the US.

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Low-Cost Curve Tracer
Uses PC-Based Scope

by Peter D. Hiscocks and James Gaston

There are times when it's extremely useful to know the voltage-current characteristic of a semiconductor device. Perhaps you're matching two transistors or you need to determine the characteristic of some unknown surplus transistor.

It's possible to obtain a VI plot by hand with an ammeter, voltmeter, and adjustable power source — and lots of patience. It is much more convenient to display the complete curve in an automated measurement using an instrument called a *curve tracer*.

On a curve tracer display, a resistor appears as a straight line with slope inversely proportional to resistance. A diode shows no current in the reverse direction and substantial current in the forward direction. Figure 1 shows an example.

Curve tracers are available from various manufacturers as an integrated instrument which includes the power supplies, switches, and X-Y display (see Resources). They're convenient to use but they are expensive and take up significant bench space. For an occasional simple measurement or when constrained by modest finances, it is possible to create a curve tracer using the XY plotting facility of an oscilloscope and some simple external circuitry.

How it Works

Figure 2 shows the circuit of a simple curve tracer. In this diagram, the device under test (DUT) is a diode, but it could be any two-terminal component.

The autotransformer provides an adjustable source of AC voltage. The 25V transformer isolates this voltage from ground and steps it down to a more manageable value. The secondary of the transformer is floating so the ground point of the oscilloscope can be established at the junction of the resistor and diode under test.

Channel A of the scope reads the voltage across the device (X axis on the curve tracer) and Channel B reads a voltage which is proportional to the current through the device (Y axis). The Channel B voltage is negative, so we invert the polarity to obtain a display where voltage increases to the right.

The demonstration circuit uses a 300Ω, two watt resistor. A peak of 20 volts across 300Ω corresponds to 66 mA peak current which is suitable for low current testing of diodes and other components. (A choice of resistance such as 250Ω or 300Ω would yield an integer value for the current scale.)

Operation is simple: Start the autotransformer at zero, then increase the setting. The voltage/current curve should appear — hopefully without cooking the DUT.

You could simplify further, by eliminating the autotransformer

Many of us grew up with oscilloscopes that included the display and controls in one stand-alone box. Times do change and so does technology.

Today's newest oscilloscope is a PDA-size unit that captures the signals and then ships them off via a USB port for processing and display on a desktop computer or on a laptop if you are immersed in field servicing. PC-based scopes even take their power from the USB connection.

Like all digital scopes, PC scopes can capture transients pre or post trigger. They provide zoom analysis and can store the display for later processing. The software runs on the PC host, permitting special math operations and digital signal processing. What's more, the PC adds potential for color printing, annotating diagrams, and immediate sending by email.

PC scopes come with a formidable array of features; in many instances, comparable to their desktop forbears. Of course, not all PC scopes are equal. For a comprehensive look at pros and cons, download our white paper: *How to Select a PC-Based Scope* at **www.syscompdesign.com/scope-specs.pdf**.

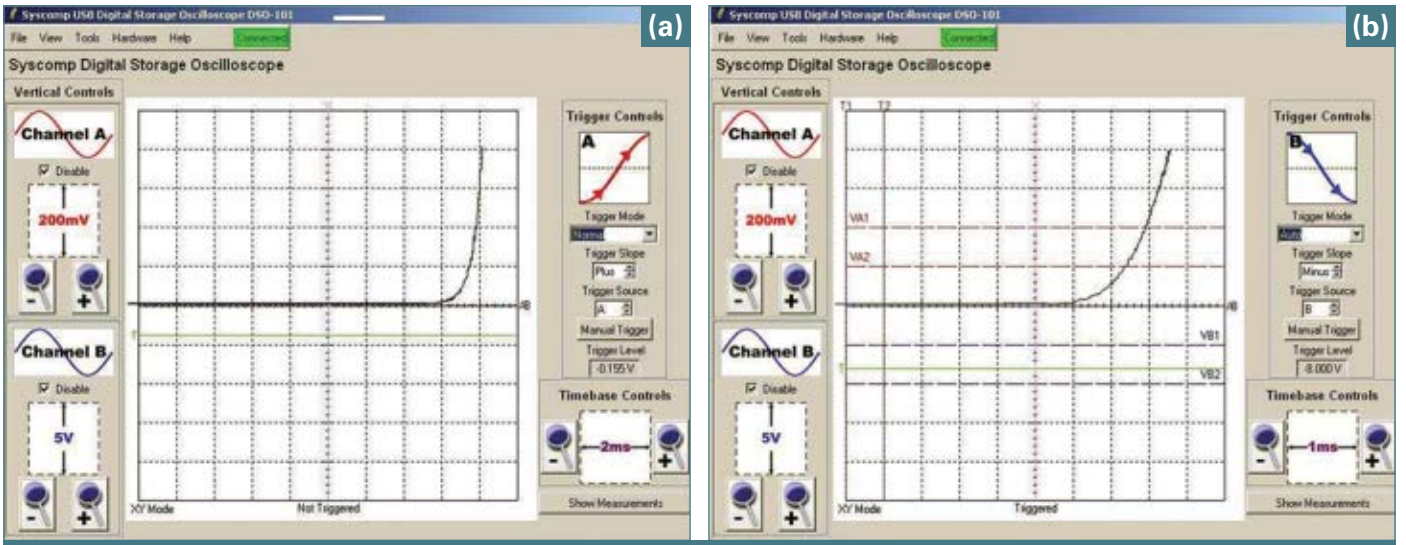
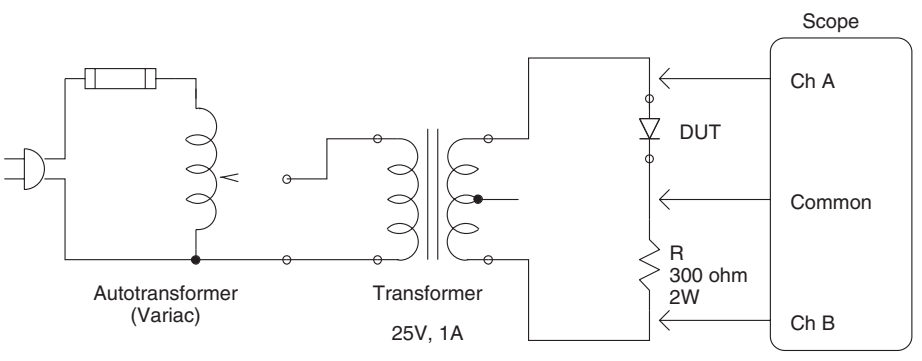


FIGURE 1. Small Signal Diodes. The horizontal scale is simply the setting of Channel A: 200 mV/div. The vertical scale is the setting of Channel B divided by the series resistance, 300Ω, that is, 5V/300Ω = 16.6 mA/div; (a) silicon diode 1N4148; (b) point contact diode.

and plugging the transformer directly into the AC line. An adjustable power resistor could then control the peak current in the DUT. However, this arrangement applies full voltage to the device under test and there might be fireworks if the test voltage exceeds the device rating. The autotransformer allows the voltage and current to be increased gradually while watching for signs of stress in the device, so it's a worthwhile investment.

For a lower-cost version, one could use a transformer with multiple secondary taps to replace both the autotransformer and the step-down transformer, and use a switch to select the desired voltage. This is the approach used in the unit designed by Craig Taylor (see Resources).

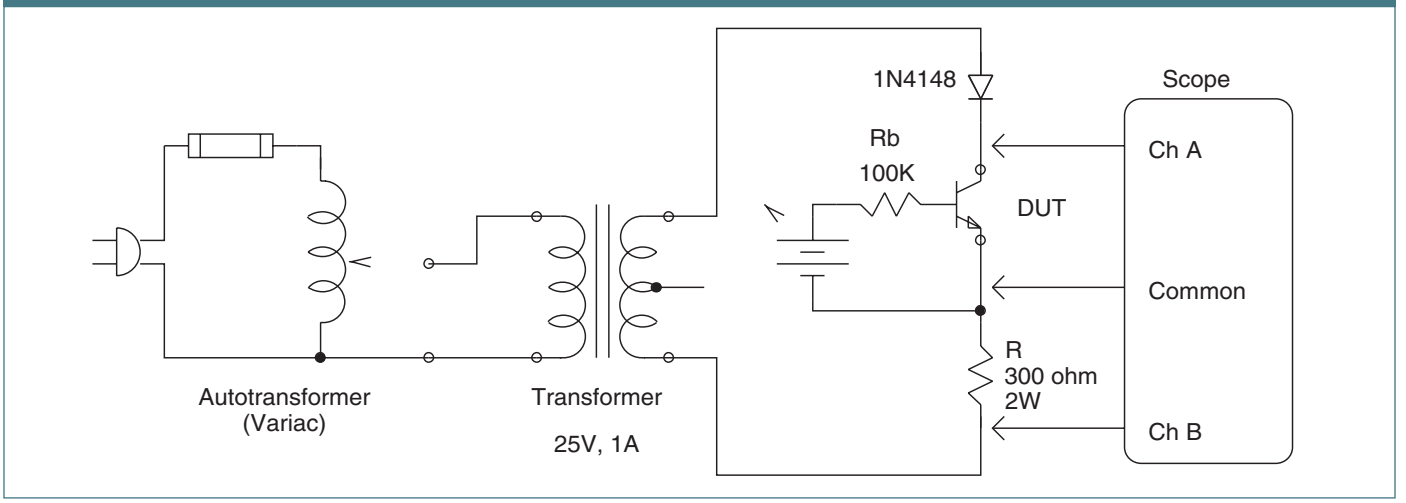
FIGURE 2. Diode Curve Tracer.



Small Signal Diodes

Figure 1 shows screenshots of the Syscomp DSO-101 PC oscilloscope functioning as the display in Figure 2, to compare two small signal diodes. Figure 1a is a 1N4148 silicon diode with a threshold voltage of approxi-

FIGURE 3. Junction Transistor Measurement.



mately 0.6 volts. Figure 1b shows an unknown type of point-contact diode with a threshold voltage of about 0.2 volts, which is characteristic of germanium. Notice that the voltage across the germanium diode approaches that of the silicon device at higher current.

Junction Transistor, Variable Base Current

For a bipolar junction transistor (BJT), the most useful display is a plot of collector current vs. collector voltage at various values of base current. So, the curve tracer circuit requires some method to inject current into the base terminal.

The current gain of the transistor (beta, or h_{FE}) is the ratio of collector current to base current. Figure 3 shows the measurement arrangement. An adjustable DC power supply drives base current through resistor R_b and around the base-emitter loop. The transistor base current is determined by the setting of the DC supply. (I used a lab DC power supply for this. You could also use a battery or a wall wart DC supply with a potentiometer across it to vary the output voltage.)

Figure 4 shows the collector curve at various values of base current.

As the base current I_B increases, the collector current I_C increases proportionally. Notice how the slope of the V_{CE},I_C characteristic increases at greater collector current. This indicates that the incremental output resistance r_o is decreasing. (It is possible to modify the scope software so that each curve can be caught and frozen on the display. This would then show the collector characteristic at various base currents, on one graph — which is the traditional method of displaying a transistor collector characteristic.)

Figure 5 confirms this with an expanded view of the BJT saturation region. The BJT requires V_{CE} to be at least 200 mV to enter its constant current region.

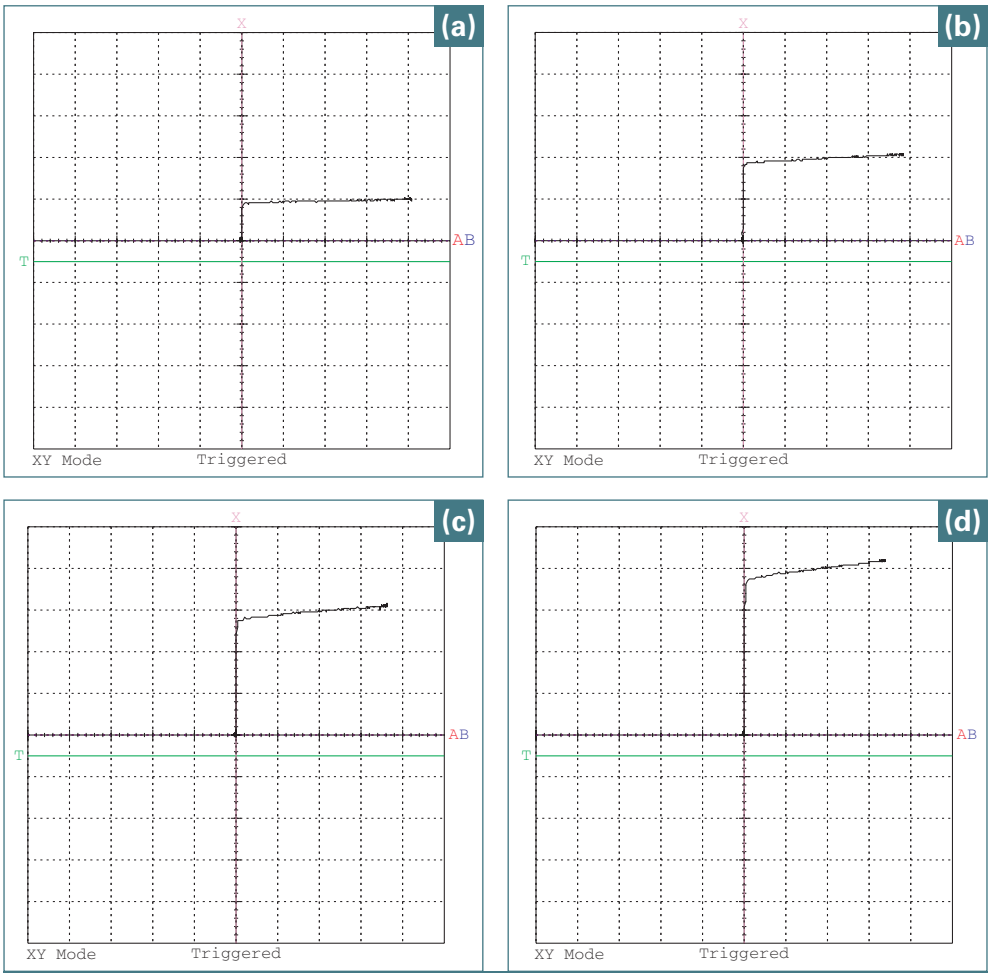


FIGURE 4. BJT, Variable Base Current: X axis V_{CE} 5V/div; Y axis I_C 3 mA/div; (a) I_b = 22µA; (b) I_b = 45µA; (c) I_b = 66µA; (d) I_b = 88µA.

The current gain β of the BJT can be determined by the relative change in collector current per unit change in base current:

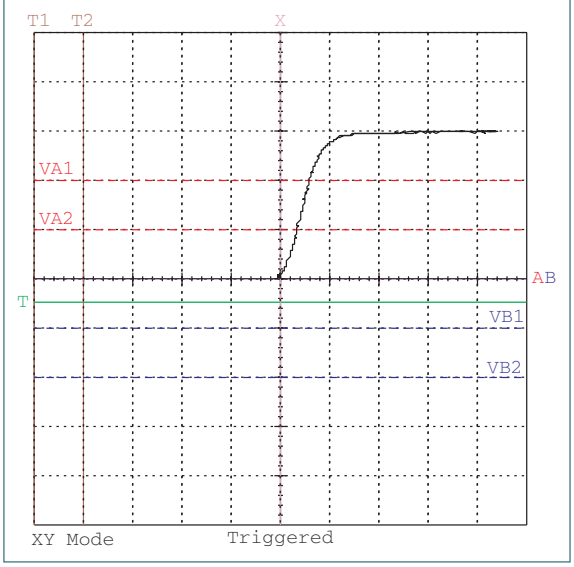
$$= \frac{I_C}{I_B}$$

Equipment Setup

Figure 6 shows the equipment setup. From left to right:

- Autotransformer for adjustment of line voltage
- 117 VAC to 24V transformer for isolation
- Device under test (lamp) and current sensing resistor
- Syscomp PC oscilloscope hardware
- Laptop computer

FIGURE 5. BJT Saturation Region: X axis V_{CE} 200 mV/div; Y axis I_C 6.6 mA/div.



RESOURCES

SYSCOMP DSO-101 PC-BASED OSCILLOSCOPE
www.syscompdesign.com
The oscilloscope used in this project.

LOW-COST CURVE TRACER USES PC-BASED SCOPE
www.syscompdesign.com/tech.htm
An extended version of this article, showing other device curves.

http://pcbunn.cithep.caltech.edu/jjb/Tektronix/tektronix.htm
The classic Tektronix 575 curve tracer.

VI CURVE TRACER
Charles Wenzel
www.techlib.com/electronics/curvetrace.html
A simple curve tracer using a tapped transformer in place of the variac and step-down transformer.

A LOW-COST AUTOMATIC CURVE TRACER
George R. Steber
QST Magazine, July 2006
www.arrl.org/qst/2006/07/steber.pdf
A small-signal curve tracer that uses the PC sound card.

FIGURE 6. Equipment Setup.

The autotransformer in this setup is *much* larger than necessary. For low currents, a sine wave signal generator could be used instead.

Summary

It's possible to measure many different semiconductor characteristic curves with the simple equipment setup shown in this article. Different measurements require different circuits, but the wiring is simple and the cost is negligible compared to a commercial curve tracer.

The Syscomp DSO-101 oscilloscope is convenient to use as a display in this application. In addition to X-Y mode, the software supports saving a screenshot or plot for incorporation into a document.

This curve tracer circuit was used to produce small currents and voltages, but it would be simple to extend the circuit to large currents and voltages. **NV**

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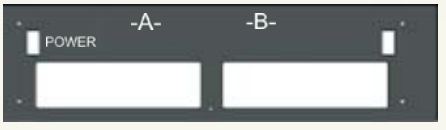

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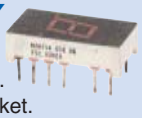

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Note: To use this transmitter as a primary control, it is necessary to use a micro controller module to split and amplify the received signal into six individual channels. See PDF spec sheet on our website for a schematic for this mod, provided by one of our customers.
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A2D Signal Processing

by Larry Cicchinelli

One of the limitations of many low cost, single supply, analog-to-digital (A/D) converter ICs today is that they have a limited input voltage range. This article discusses various ways to implement input processing to allow these devices to operate in the real world. I use the ADS7870 as an example A/D, but the equations and samples are generic enough so that you can configure the circuits for other devices.

The ADS7870 has three possible internal voltage reference values. We will assume that the 2.048V reference has been selected and that its programmable gain amplifier is set to 1.0. When used in its single ended mode, the A/D then has a useful input voltage range of 0 volts to V_{ref} – 1 LSB and has 11 bit resolution.

When used in its differential mode, the useful input voltage range increases to $-V_{ref}$ to V_{ref} – 1 LSB (relative to the + input) and therefore has 12 bits of resolution where the MSB becomes the sign bit. However, the input voltage must always be positive.

Some A/Ds have an input voltage limit of 2*Vref, so be sure to keep that in mind when determining the maximum input voltage.

For the circuits in Figures 1 and 2, the value of R2 should be adjusted based on the input resistance of the A/D. However, if the calculated value is much greater than the A/D resistance, then simple calibration should be all that is required.

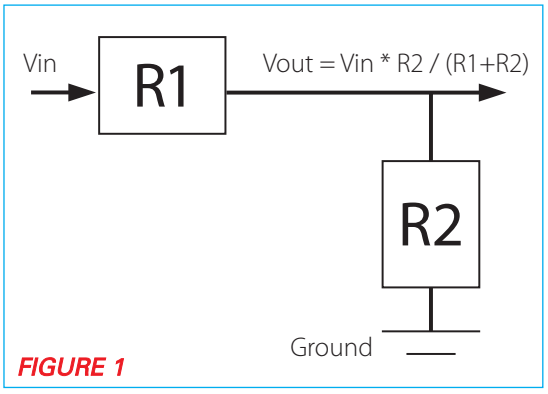


FIGURE 1

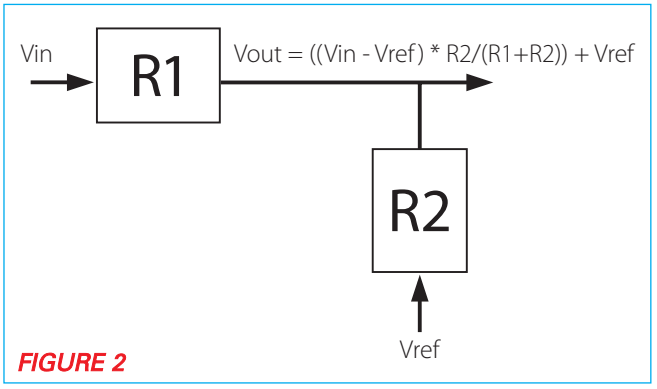


FIGURE 2

The simplest form of scaling only works for unipolar inputs and is a voltage divider (see Figure 1). If your system only needs to measure between 0 volts and some positive voltage greater than the reference, then this might be adequate. By rearranging the equation in the figure and specifying the required input resistance, you can determine the value for R2:

R2 = Vout * R1 / (Vin - Vout)

If R1 = 100K and Vin = 10V when Vout = 2.048V, then R2 = 25.7K

Just as a practical matter it would be a good idea to use a slightly higher value as the maximum for Vin just to insure that you have some "headroom." If we use 10 volts as the actual maximum Vin, the scale factor for converting from A/D counts to volts is 10/2047 = 4.8851mV/count (2047 is the maximum count value for an 11 bit device). This can be used but is somewhat awkward. It also does not allow for headroom. A better solution is to round up the value calculated above to 5 mV. This yields a maximum input voltage value of 10.235 volts.

The applied voltage can be calculated from the count value as measured by the A/D:

Vin = Count * .005

This is similar to the circuit in Figure 1 except that it allows you to measure bipolar voltages.

You can see that if Vref = 0, the equation reduces to the same as in Figure 1. Solving the equation for the reference voltage yields: Vref = Vout(R1+R2)/R1 – Vin*R2/R1.

"Now what?" you may ask. The next step is to set Vout = 0 (because the minimum input voltage to the A/D must be 0V) and see what happens: Vref = -Vin*R2/R1. If we assume that the largest negative input voltage will yield Vout = 0, then Vref must be positive. Substituting -10 in the above equation yields: Vref = 10*R2/R1.

Now let's set Vout = 2.0V, a little below the maximum allowed by the A/D converter. This will be achieved when Vin = 10V. The equation becomes: Vref = 2*(R1+R2)/R1 – 10*R2/R1.

We now have two equations with three unknowns. We should now pick a value for R1 since it is the major contributor to the input resistance. As in the first example, let's make it 100K. The two equations become:

Vref = 10*R2/100K *and*
Vref = 2*(100K+R2)/100K – 10*R2/100K

This allows us to solve for R2 since:

10*R2/100K = 2*(100K+R2)/100K – 10*R2/100K

which reduces to: R2 = 200K/18 = 11.1K. If you want to be really exact, the value of R2 should take into account the input resistance of the A/D. Although the error incurred by not including the input resistance can be compensated by properly calibrating the system.

Now we can solve for Vref: 10*11.11K/100K = 1.111V.

To check, we can substitute an input voltage back into the equation of Figure 2:

Let Vin = 10v:
Vout = (10-1.111)*11.1K/ (100K+11.1K) + 1.111
Vout = 8.889 * .1 + 1.111 = 1.999

Let Vin = -10v:
Vout = (-10-1.111)*11.1K/ (100K+11.1K) + 1.111
Vout = -11.111 * .1 + 1.111 = 0.0001

Without roundoff errors, the results are exactly 2.0 and 0.0, respectively.

Op-amp Discussion for A/D Converter Scaling

Now let's look at the circuit in Figure 3. It is based on the following characteristics of an ideal operational amplifier:

1) Infinite input resistance

2) 0 volts between the two inputs – in a properly configured circuit

3) 0 ohms output resistance

Since the input resistance is infinite, there is no current flow into the inverting input; therefore, I1 across R1 must equal I2 across R2. Also, the voltage being forced on the positive input will be present at the inverting input. These two characteristics result in Formula (1).

(1): (Vin – Vref)/R1 = (Vref-Vout)/R2

Rearranging the formula allows you to solve for Vout in terms of Vin and Vref:

(2): (Vin – Vref)(R2/R1) = Vref–Vout

(2a): Vout = Vref – (R2/R1)(Vin – Vref)

(2b): Vout = Vref(1 + R2/R1) – Vin(R2/R)

IMPORTANT: Since Vin is applied to the negative input, Vout(min) occurs at Vin(max).

This circuit may be used to implement a function similar to that in Figure 2, as we did previously, but with higher input resistance. The easiest place to start is to determine the ratio of the input and output voltages. This will determine the ratio of R1 and R2. If you need an input voltage range of -10V to +10V and an output voltage range of 0V to +2.048V, the ratio is 20/2.048. The calculations will be easier if the input voltage range is expanded to: -10.24V to +10.24V. This yields a ratio of 20.48/2.048 = 10.0, as well as giving the circuit some headroom.

The voltage values used to calibrate any of the above systems can be chosen approximately as:

Vmincal = Vmin + Vspan/20
Vmaxcal = Vmax – Vspan/20

This enables calibration at the 5% and 95% points. It is not a good idea to calibrate at the endpoints since your applied voltage may be slightly outside the measurable range.

Where:

Vmincal = the minimum applied calibration voltage

Vmin = minimum allowed input voltage

Vmaxcal = the mamimum applied calibration voltage

Vmax = maximum allowed input voltage

Vspan = Vmax- Vmin NV

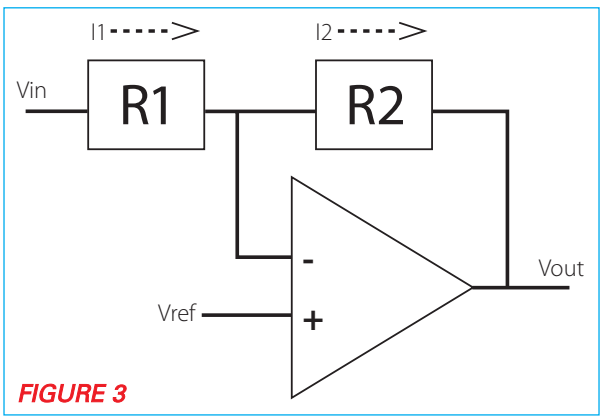
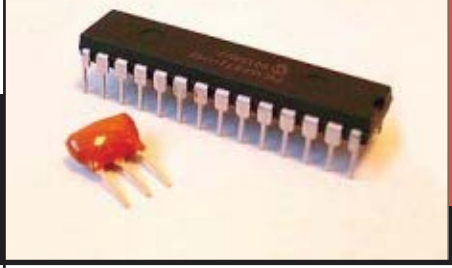


FIGURE 3



PICAXE PRIMER

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■ BY RON HACKETT

PLAYING MUSIC AND WATCHING LIGHTS

IN THE FIRST INSTALLMENT OF THE PICAXE PRIMER, we took a look at the 08M's music making capabilities and used the super simple "play" command to play "Rudolph the Red-Nosed Reindeer." This month, we'll expand our repertoire by exploring the "tune" command, which will enable us to play any tune we choose. As I mentioned last time, there are nearly 1,000 tunes available for free downloading at the Revolution Education website (www.rev-ed.co.uk/picaxe/).

Hopefully, you have already visited RevEd and downloaded all the available tunes. If not, now is the time! Just go to the RevEd software page and scroll down to the "Additional Resources" section near the bottom of the page. You will find five zipped files containing the tunes. In addition to tunes, the 08M can play any monophonic ringtone in RTTTL format (the kind used on most Nokia cell phones). The Additional Resources section of the RevEd software page also contains two zipped ringtone files, as well as links to websites where you can download more free ringtones.

Downloading a tune file to a PICAXE chip is a simple matter of copying and pasting the tune into your program; ringtone files, on the other hand, require a conversion process that utilizes the Programming Editor's "Tune Wizard," which is a much more involved process. Also, the majority of the RevEd ringtone files have already been converted to tunes and also appear in the tune folders.

For these reasons, we will focus on the tune files. Later, if you want, you can explore the ringtone conversion process. Be sure to read the documentation on the tune command (especially the section on the Tune Wizard) in Part 2 of the PICAXE manual.

TUNE FILES

Working with tune files isn't quite as simple as playing "Rudolph," but it's still fairly easy. All we need to do is unzip RevEd's tune files, copy the tune we want from one of the folders to the clipboard, paste it into our own program, and download the program to the 08M. Before we do, however, I have a couple of cautions to mention.

```
'==== Davey.bas ======== 2007.12.10 ======== Ron Hackett ====

'       This program runs on a PICAXE-08M processor. It plays
'       "Davey Crockett" and alternately blinks LEDs on outputs
'       0 & 4 (pins 7 & 3) in time with the music.


'==== Directives ====
       #com 1          ' specify correct com port
       #picaxe 08M     ' specify which PICAXE chip


'==== Begin Main Program ===================================

main:   ' "Davy Crockett" tune from RevEd tune files

tune 3, 5, ($25,$65,$67,$69,$67,$65,$60,$22,$25,$E0,$25,$27,
$29,$67,$65,$27,$67,$69,$E7,$20,$60,$60,$25,$60,$60,$22,$62,
$62,$E7,$24,$64,$64,$24,$64,$62,$20,$62,$64,$E5,$29,$C0,$02,
$42,$40,$29,$60,$60,$60,$60,$24,$27,$E5,$2C,$29,$C0,$02,$42,
$40,$29,$60, $60,$60,$60,$24,$27,$E5)

wait 2                  ' 2 second delay between repetitions

goto main               ' do it again, forever
                        ' or until you can't stand it any more!
```

■ FIGURE 1. Basic program to play "Davey Crockett."

First, music data is fairly memory-intensive; it doesn't take long to fill up the 08M's 256-byte program memory. Three or four tune files is the most that an 08M can store. Also, as I explored the contents of the zip files, I made two important discoveries. First, these files were evidently "composed" and contributed by people with a wide range of musical talent — some of them don't sound quite the way they should, and I think this is a composer-related issue more than a PICAXE issue. (I hope I put that tactfully!)

Secondly, when it comes to popular culture, I am definitely what you would call "challenged," so I couldn't even tell whether many of the songs sounded the way they should. One of the songs in the second zip file that did sound reasonably good to me was "Davey Crockett" (see what I mean about being culturally challenged?), so let's use that one for our first tune program.

Once you have unzipped the second folder of tunes, all you need to do is double-click on the Davey Crockett file. It's just a text file, so it should open in the NotePad accessory. Next, "select all" and copy the contents of the file to the clipboard. Finally, run the PICAXE Programming Editor, create a simple program, and paste the contents of the clipboard into your program. At this

point, another note of caution is in order — music files usually create very long lines in your program. Don't try to break up these long lines by inserting a "return" character — it will confuse the Programming Editor. If you want to break up a line, insert a "space" character instead — that way, the editor will interpret the music data correctly.

Figure 1 presents the final program file formatted with a couple of extra spaces in the long line. I also made one minor change to RevEd's file. The first parameter of the tune command determines whether the LEDs will blink as they did with Rudolph (again, see the documentation). I changed the parameter's value from zero to three so the LEDs will blink.

When you have completed editing your program, download it to the same 08M circuit we used last time (in the December '07 issue of *N&V*) to play Rudolph — Davey Crockett will play repetitively. When you have had enough, powering down your 08M circuit will silence Davey.

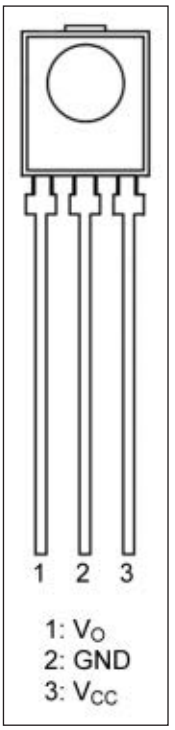
You may want to take some time to experiment with some of the other tune files to see how they sound. Whenever you want, you can also read the tune command documentation and try your hand at converting ringtone files to tune files. If you run into trouble, let me know and I will see if I can help. If you have some musical background, it's also possible to use the tune documentation to compose entire melodies of your own. If you are successful in doing so and would like to be "published," I would be happy to post your tune on my website.

INFRARED COMMUNICATION

At this point, we're going to shift gears to take a brief look at the 08M's IR capabilities. Almost all PICAXE chips — including the 08M — have powerful built-in commands for IR input and output. Let's begin with IR input.

There are actually three IR input commands: infrain, infrain2, and irin. Each of these commands functions with a different subset of PICAXE processors. There are some significant differences between the three IR input commands (again, refer to the documentation for details), but all three of them are able to decode IR signals from any TV remote capable of transmitting the SIRC (Sony InfraRed Control) protocol, which not only includes all Sony IR remotes but also any universal remote capable of sending the Sony signals.

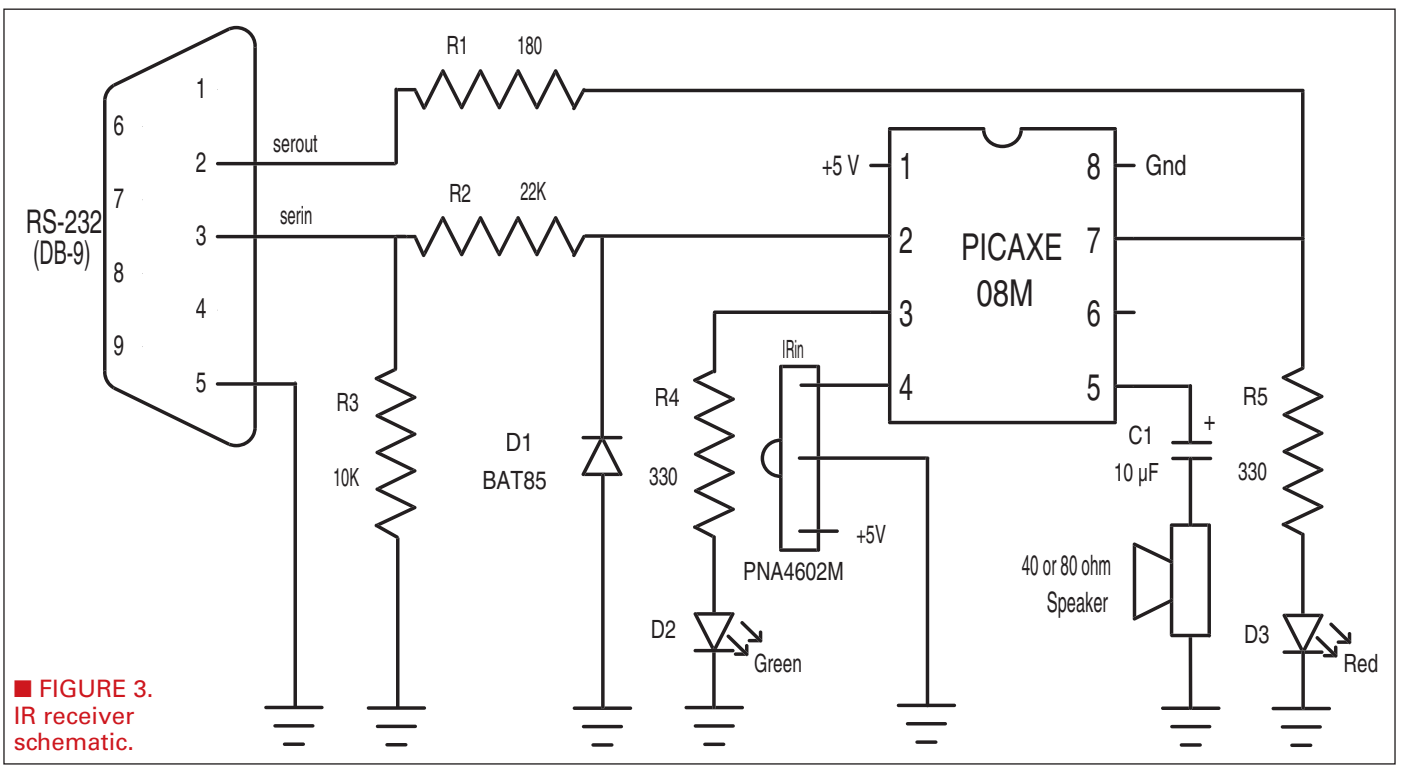
■ FIGURE 2. PNA4602M IR receiver pinout.



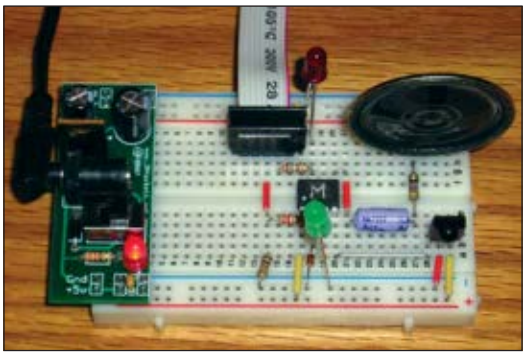
Over the years, I have collected six or seven universal remotes; when set up to send signals to a Sony TV, they all function perfectly with the IR project we are about to discuss. So, just about any universal remote should work fine — just be sure you program your remote with the correct code for transmitting Sony TV signals.

The 08M uses the infrain2 command, so that's the one we'll focus on. The SIRC protocol (and many others, as well) transmits its data by modulating a 38 kHz carrier wave, so it is necessary to demodulate this wave to extract the useful information on the receiving end of the IR link. Fortunately, there are several integrated IR decoder units on the market.

We will be using the Panasonic



■ FIGURE 3. IR receiver schematic.



■ FIGURE 4. IR receiver breadboard circuitry.

PNA4602M unit because it's readily available (see the Sources sidebar) and it requires no additional external circuitry. The connections couldn't be simpler (see Figure 2): pin 1 (V-out) connects directly to the IR input pin of the 08M (input 3, external pin 4); pin 2 is ground; and pin 3 is +5V. The 08M circuit for IR reception is presented in Figure 3, and a photo of the breadboard circuitry is shown in Figure 4.

The first thing you will notice is that the circuit includes all the music circuitry that we have been working with up to this point. Of course, this is not at all necessary for IR reception, but I have left it in because we will find a use for it later in this column.

We will also be using one of the two LEDs from our music circuit. It's the one attached to output 4 (external pin 3) of the 08M. In the music circuit, the LED's color didn't matter, but for our IR explorations, make sure it's a green LED — we will see why that's important shortly.

■ FIGURE 5. Infra values returned by infrain2 command.

TV Remote Control Ke	Infra Value	Infra Value + 1
1	0	1
2	1	2
3	2	3
4	3	4
5	4	5
6	5	6
7	6	7
8	7	8
9	8	9
0	9	10
Channel +	16	17
Channel -	17	18
Volume +	18	19
Volume -	19	20
Mute	20	21
Powe	21	22

The only other circuitry we're adding is an additional (red) LED and current-limiting resistor on the 08M's output 1 (external pin 7). As usual, you can't see the current-limiting resistor in Figure 4 because it's integrated into the LEDs that I used (see Sources).

Before we discuss the software that accompanies our IR circuit, it's important to understand how the infrain2 command functions. Whenever an infrain2 command is executed in a program, the program pauses and waits for the reception of an IR signal. There is no time-out feature for the infrain2 command; if no IR signal is received, the program will be stalled forever at the location of the infrain2 command!

The usual way to get around this issue is to include interrupts in the program (see the documentation on the setint command). However, this can quickly get complicated and difficult to manage. My experience is that it's much simpler to dedicate an 08M to the single process of receiving IR signals and relaying them to a second processor via a serial link. That way, the second (master) processor is free to carry out a variety of tasks without being tied up waiting for IR signals.

When the infrain2 command does receive an SIRC signal, it automatically decodes it and stores the resulting value in a special variable named infra, which is actually another name for one of the PICAXE standard byte variables, namely b13. As a result, in any program that includes IR signal reception, it is important to not use b13 for any other purpose — to do so will almost certainly cause the program to malfunction.

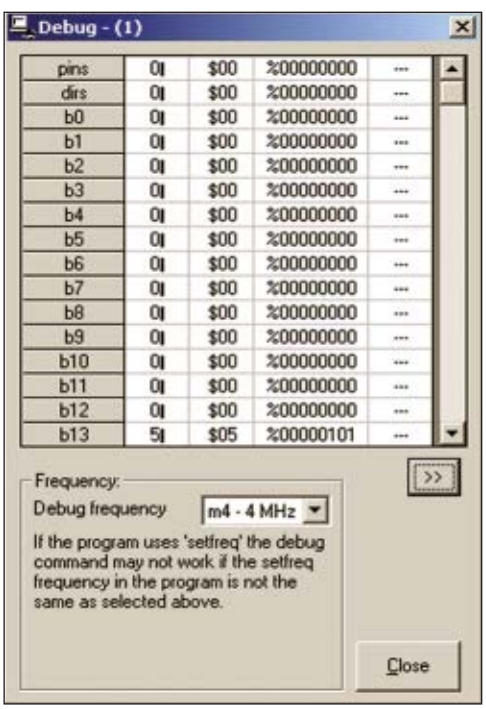
The second column of Figure 5 presents the infra values resulting from various key presses on a TV IR remote when the SIRC protocol is enabled. As you can see, the digits one through nine unfortunately each return a value that is one less than the original digit's value. To correct this situation, the third column in Figure 5 simply adds 1 to each value of infra, so that the values for the digits 1 through 9 match the corresponding digit, which is what we will do in our IR program.

THE PICAXE DEBUG COMMAND

At this point, we could probably jump directly to our first IR reception program without discussing the debug command because our program is a simple one and is not likely to require debugging. However, I think it's a good idea to explore the debug command in advance of actually having a problem. That way, you will be prepared to effectively deal with program bugs when they do occur.

Whenever a PICAXE program encounters a debug command, it uses the PC programming connection to serially transmit the current value of all variables to a special window in the Programming Editor called the Debug Window (see Figure 6). This is a fairly large amount of data, so each debug command can significantly slow down the running of a program. Of course, once the program is functioning correctly you can remove all the debug commands.

There are a couple of points worth noting about the Debug Window in Figure 6. The first column lists all of the PICAXE standard variables, as well as



■ FIGURE 6. PICAXE Debug Window.

pins and dirs, which are two Special Function Variables. There isn't enough space to discuss them this month, but you may want to read the documentation on Special Function variables in Part 2 of the manual because they can be very useful in a program.

The remaining 14 entries in column one (b0, ... b13) are the regular byte variables and, if you click on the button displaying the ">>" symbol, the Debug Window expands to show the seven word-variable equivalents for the 14 byte variables. (If all this is confusing, reading the section on General Variables in the manual should clarify things.)

The remaining four columns display the value of each variable in decimal, hexadecimal, binary, and ASCII values, in that order. Only printable ASCII values are displayed and all values below decimal 33 are non-printable, so the fourth column in Figure 6 just displays elipses.

Finally, the number in parentheses at the top of the window (after Debug) indicates how many times a debug command has been executed since the program started.

Our first IR reception program (shown in Figure 7) demonstrates how the debug command functions. Essentially, the program consists of three commands in the main loop: infrain2, which waits for an incoming IR signal and then decodes it; infra = infra +1, which adds 1 to each value of infra so that the values for the digits 1 through 9 match the corresponding digit as discussed above; and debug, which transmits the received infra value back to the Debug Window on the PC, along with all the other variables that we haven't implemented at all (so their values are all 0).

Type the program in Figure 7 into the Programming Editor and give it a try. If you are using a universal TV remote, be sure you have entered the appropriate code to enable the SIRC signals. If it's a multi-device remote, also press the TV key to be sure you are transmitting the TV codes.

Once the program is running, press a key on the remote. Each time you do so, the adjusted infra value (as per the third column of Figure 5) should appear in the b13 row of the Debug Window. If it doesn't, check your program for typos and/or logic errors, and try again. You will also see the LED on output 0 flickering after each key-press on the remote. This is because output 0 is also the Serout connection to the PC. The data being sent is what causes the flickering.

■ FIGURE 7. Infrain2Debug Basic program.

```
' === Infrain2Debug ======== 2007.11.28 ======== Ron Hackett ===
'
'     This program runs on a PICaxe-08M, decodes the Sony SIRC
'        protocol and displays results in the PICAXE Debug Window.


' === Directives ===========
        #com 1              ' specify com port
        #picaxe 08M         ' specify PICAXE chip


' === Begin Main Program ======================================

main: infrain2              ' wait here for infra-red signal

        infra =infra + 1    ' add 1 (so digits & values match)

        debug               ' display results in debug window

        goto main           ' do it again, forever
```

DISPENSING WITH DEBUG

Once you have the above program working correctly, the debug command has done its job and we're ready to re-write our program so that it can function independently of the PC. In order for it to do so, we'll use a code that we can output to the red LED on output 0 (pin 7) and the green LED on output 4 (pin 3) of the 08M. The code I used is very simple; each red flash equals five and each green flash equals one. For example, if the "8" key is pressed on the remote, you should see one red and three green flashes. The main loop of the program (see Figure 8) merely waits for an incoming IR

■ FIGURE 8. Infrain2Demo Basic program.

```
' === Infrain2Demo ======== 2007.11.28 ======== Ron Hackett ===
'
'     This program runs on a PICaxe-08M, decodes the Sony SIRC
'        protocol and displays results using a simple 2-LED code.


' === Constants ============
        symbol    LEDred = 0            ' red LED on output0 (pin 7)
        symbol    LEDgrn = 4            ' green LED on output4 (pin 3)


' === Variables ============
        symbol    red = b0              ' used to store # of red blinks
        symbol    grn = b1              ' used to store # of green blinks


' === Directives ===========
        #com 1                          ' specify com port
        #picaxe 08M                     ' specify PICAXE chip


' === Begin Main Program ======================================

main: infrain2                          ' wait here for infra-red input
        infra = infra + 1               ' add 1 so digits correspond

        red = infra / 5                 ' compute # of red blinks
        grn = infra //5                 ' compute # of green blinks

        do while red > 0                ' do red blinks
           high LEDred
           pause 100
           low LEDred
           pause 300
           red = red - 1
        loop

        do while grn > 0                ' do green blinks
           high LEDgrn
           pause 100
           low LEDgrn
           pause 300
           grn = grn - 1
        loop

        goto main                       ' do it again, forever
```

signal and then implements our code to flash the two LEDs to indicate the value of the received signal.

In order to understand how the program in Figure 8 functions, we need to be clear about the difference between the / and // mathematical operators, which are discussed under the "let" command in the documentation: / is the standard division operator and // is the modulus division operator. In other words, / returns the (integer) quotient of a division and // returns the remainder.

For example, 8 / 5 = 1 and 8 // 5 = 3, because five divides into eight once with a remainder of three. The program uses these two operators to compute the red and grn values for each remote key-press and then each do...loop blinks the LEDs accordingly. I selected the do...loop structure to implement the LED code because it allows for testing at the beginning of each iteration of the loop, which enables us to exit the loop at the correct point in the count-down.

PROGRAMMING CHALLENGE

By now, you are probably wondering why we left the speaker output in our IR circuitry, since we didn't use it in either of our IR programs — well, the reason is that I have a programming challenge for you! In the first installment of the Primer, we briefly explored the four songs that are built into every 08M (the details are in Part 2 of the manual under the "play" command). The challenge is to write a program that responds to IR input as follows: If the user presses 0, 1, 2, or 3 on the remote, the corresponding built-in song will play; if he or she presses any other key, an annoying buzzer will sound (see the "sound" command documentation for help with this part). See what you can come up with, and I will post one possible solution on the PICAXE PrimeD Blog at **www.nutsvolts.com/blogs/index.php?/site/categories/C18/** before the end of February. Have fun!

ONE FINAL NOTE

That completes our brief introduction to IR input on the 08M. It's a very powerful feature that can be used as the basis for a remote-controlled robot, a wireless input device for any project that requires user input, or many other projects. Combined with the infraout command (you probably know what I will say next — see the Manual for details!), it can provide a short-range wireless data link between two PICAXE projects and/or automated control of any Sony audio/video equipment. If you come up with an interesting application, let me know about it! You can reach me by email at Ron@JRHackett.net. **NV**

SOURCES

PICAXE-08M:
www.JRHackett.net; **www.phanderson.com**; or **www.picaxe.co.uk**

Five-volt Resistorized LED
Panasonic PNA4602M IR Decoder
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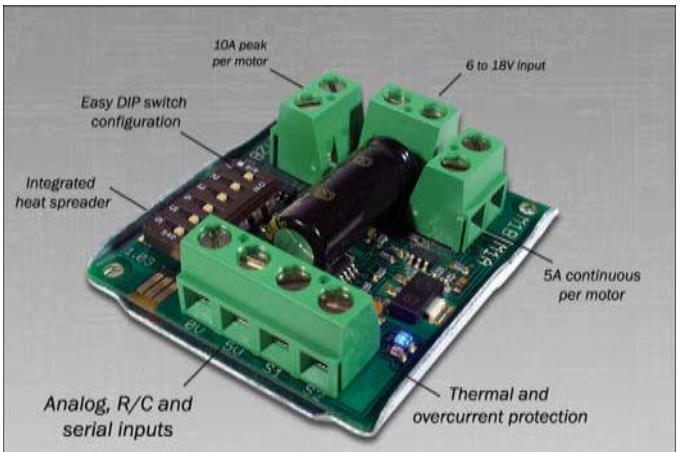

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BY LOUIS E. FRENZEL W5LEF

A FEMTO IN YOUR FUTURE? What the devil is a Femto?

I SUPPOSE IT HAD TO HAPPEN SOONER OR LATER. With indoor cell phone usage as poor as it often is, it was inevitable that someone would come along to solve that problem. And here it is — the femto cell. It just could be one of the next big electronic purchases you make.

A femto cell is a miniature cell phone basestation designed to operate inside your home to give you improved indoor cell phone coverage. Cell phones are low power UHF or microwave two-way radios designed to operate outdoors. Their typical range is a few miles at most and even shorter in most cases usually because of environmental limitations. Radio wave propagation in the UHF and microwave regions is strictly line-of-sight (LOS) and heavily impacted by obstructions like buildings, trees, mountains, and especially the walls of buildings. Reflections causing multipath signals are always a problem.

If you are using your cell phone outside, you have a much better chance of hitting the closest cell site antenna tower and getting a clean clear signal. But if you are in an area obstructed by trees or surrounded by tall buildings, cellular service could be poor to non-existent. It is even worse if you are indoors since the signals are greatly attenuated by walls, ceilings, furniture, and the like.

Many people complain about their bad to worse indoor cellular coverage, but just remember, these phones were not optimized for indoor operation. Yet, that is not how people tend to use them.

It has been estimated that over 50% of all cell phone calls originate from indoors. In fact, some even say that better than 70% of calls come from inside homes or from office buildings. Think about your own cell phone usage. Is it mostly indoors or outdoors? In any case, it is amazing that performance is as good as it is. People adapt and move their positions to optimize the signal when calling from indoors. They get near a window or move around a room until they get one or more "bars" of signal. Or, as a last resort, go outside.

This problem of poor indoor cellular coverage has been resolved by the cell carriers for years by using smaller basestations (cell sites) we call micro or pico cells. These compact basestations are designed to be installed inside a building or other public place. They may sit on top of a tall building or be mounted on the wall inside an airport.

Micro means small (10^{-6}) while pico means really small (10^{-12}). Now, along comes the femto cell. Femto literally means 10^{-15} or one thousandth of a trillionth. Even smaller. Femto cells are very small but complete low power basestations designed to be used in the home.

■ FIGURE 1. Femto cells made by Airvana of Chelmsford, MA. It incorporates a 3G radio transceiver, processor, Ethernet interface, and the antenna.

Figure 1 shows what one looks like. It's like a cable TV set top box or a wireless LAN router in size. Your cell phone will talk to it rather than an outside basestation when you go to make a call. With such close range, your connection will be sure and good.

THE BACK HAUL PROBLEM

All basestations have to get connected to the main telephone networks somehow. This is done by their back haul connection. This connection is made in a variety of ways, depending upon where the basestation is. The most common connection is one or more T1 data lines that all telecommunications companies use. Recall that these lines carry up to 24 digital voice calls in a time division multiplexed mode at a data rate of 1.544 Mb/s. Sometimes the back haul is by a fiber optic cable or by a short range microwave point-to-point radio.

In a femto cell, the back haul connection is your high speed Internet broadband connection. (See Figure 2.) That would be a cable TV data service

or a DSL line. The femto cell plugs into this line and sends the call from you phone back to the Internet service provider who sends it through the Internet to your cellular provider.

THE GOOD NEWS AND THE BAD NEWS

Femto cells solve the indoor performance problem for sure. In fact, it is expected that with great indoor cell service, more and more subscribers will drop their wired telephone connection. Wired phone subscriptions have been in decline for years and many under 30 years of age already rely solely on their cell phone for phone service.

Femtos also solve the capacity problem of some cell sites in a carrier's system. Most basestations can only handle so many simultaneous calls. This typically amounts to several hundred calls depending upon the technology used and environmental factors. If you try to make a call in a high density population area during a really busy time, you just won't get any service if the cell site is at capacity. That doesn't happen too often as most cell phone companies have a sufficient number of cell sites to handle their subscriber load. But service denials do occur, during emergencies for examples, when everyone is trying to call for help or to check on a friend or family member.

The femto cell will help offload some of that traffic from existing base stations. That will only occur in residential areas where a sufficient number of subscribers actually go for the femto service. But overall, it helps to minimize the need for extra costly standard basestations with their towers and costly land leases, power consumption, and related expenses. Femtos are a real plus for the carriers, assuming a critical mass of subscribers.

Femtos should also boost performance of any cell phone data service you may have. For example, if you have a high speed data card for your laptop, it will probably perform much better on your femto than with an outside basestation. Data rate usually adjusts automatically to the signal conditions. The stronger the signal, the faster the data rate.

The downside to femtos is the potential interference they can cause to nearby standard basestations and to one another. A femto cell is a low power radio and its power will be only milliwatts to limit its range to inside the home. Given the nature of wireless, it is anyone's guess how far a signal will travel. A femto cell in one apartment may interfere with the femto in an adjacent apartment. Or, it could interfere with a standard basestation only blocks away. It remains to be seen.

The actual positioning of the femto cell is critical to getting optimum coverage from your cell phone but also critical to minimizing interference with those around you. The carriers haven't completely figured out how to deal with that yet, but they are working on it.

Another issue is the handoff problem. When you move around with your cell phone, you will often go out of range from the basestation you connected to originally. You will typically move into the coverage area of an adjacent cell site. The phone system is designed to seamlessly hand off your connection from one site to another without you even knowing it. That same arrangement has to be implemented in the femtos. If you initiate the call in your home, you will want the call to continue as you go outside or get in the car or whatever. And vice versa. If you get out of you car and go inside, the phone must switch from the external cell site to your femto without disconnecting or other fuss. Not an easy thing to do, but it is usually part of all cell phone technology.

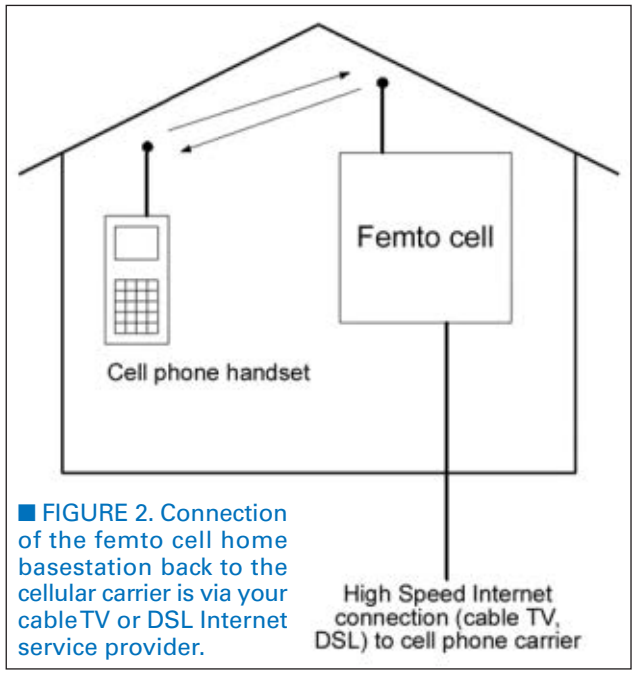
WHERE CAN YOU GET A FEMTO CELL?

In most areas, femtos are not yet available. They are still largely under development, test, and study. Two active test areas are Denver and Indianapolis where Sprint is in field trials with a femto made by Samsung. There are other pockets of tests occurring on a small scale to determine the problems and the solutions before large scale deployment; 2008 is expected to be a testing year with potential roll-out in 2009. The activity will vary with the carrier.

Virtually all femtos are expected to be 3G basestations. The term 3G refers to the third generation of cell phones with high speed data service. If you have an AT&T or T-Mobile cell phone, 3G means a phone that uses wideband code division multiple access (WCDMA) possible with the high speed packet access (HSPA) data option. If your carrier is Verizon, Sprint, or Alltel, the 3G technology is called cdma2000 EV-DO (evolution-data optimized). If you have an older phone, you will need to upgrade to use a femto. Not a bad deal if you really need good indoor coverage and a fast data option.

Every carrier is looking into femtos and there are a dozen or so manufacturers standing by to make them. Will they be a big hit? It is anyone's guess at this point. It is more a way for your cellular company to get your money, but in return, you will get even better service, greater reliability, and higher data speeds.

Watch your local area for the availability in the months to come. **NV**



■ FIGURE 2. Connection of the femto cell home basestation back to the cellular carrier is via your cable TV or DSL Internet service provider.

■ BY FRED EADY

INTRODUCING THE 32-BIT PIC!

I CAN STILL REMEMBER FIDDLING WITH MY very first PIC project, which was based on (at that moment in time) the brand new and unbelievable PIC16C54. I don't recall ever complaining about the size of the PIC16C54 SRAM or its 1 µs instruction cycle time. And, I don't recall ever filling up a PIC16C54's program memory as we all programmed in assembler back then. As time passed, I quickly "outgrew" the PIC16C54's limited I/O system (12 I/O lines) and moved up to using the "bigger" PIC16C55 device (20 I/O lines) in my projects.

My late friend and mentor, Bill Green, was deep into embedded Z80 development at that time. Bill never really liked PICs as he didn't see how I could do things he was doing with his Z80s with a PIC that seemed in comparison to have so few resources. With no disrespect to Zilog and their magnificent family of Z80 products, back then I felt that there was nothing I could not do with a PIC. Every time I ran up against an application that the current PICs could not easily handle, Microchip would punch out a more advanced part that filled the bill. That trend still continues to this day. I honestly believe that Bill would be "PICing and Grinning" with the rest of us if he were here today.

I literally wore out a pair of EPROM erasers during my PIC16C5X period as I prototyped all of my PIC projects using the JW package, which was comprised of a ceramic body with a quartz window over the PIC's EPROM-based program memory innards. These days, you can still use the PIC16C54 in a design but you won't have to dust off that old EPROM eraser as the PIC16C54 has been replaced with the PIC16F54, which can zip along at 20 MHz. As for my introduction to Flash program memory, I saw the writing on the wall when the PIC16F84 was introduced. I hopped on the Flash bandwagon at that time and have never jumped off.

To this day, I've worked on only one project where I completely filled up a PIC. Believe it or not, I filled the PIC's program memory with assembler code! I guess Microchip wants to keep my 0-1 program memory-filled record intact. I just got my hot little hands on a member of Microchip's new 32-bit PIC family and it looks like we will have to do some pretty serious coding to exhaust its very generous program memory and SRAM resources. With that, this month we'll take a look at the subsystems that make up the new PIC32MX and build up some super simple hardware to allow you to evaluate Microchip's new 32-bit monster microcontroller.

4 -> 8 -> 16 -> 32 BITS

Although the PIC is in a microcontroller class of its own, this whole microcontroller thing actually started with a four-bit microprocessor called the 4004, which was introduced to us in November of 1971. The Intel 4004 consists of 2,300 transistors that can do the job of the 18,000 vacuum tubes found in the very first electronic computer, the ENIAC. The Intel 4004 was a member of the MCS-4 family, which included a supporting 4001 ROM-based program memory device, the 4002 RAM device, and 4003 I/O port/shift register device. One thousand transistors later, the eight-bit 8008 microprocessor appeared. The rest is history as the Intel 8088 became the darling of the early IBM personal computers and their clones. Oddly enough, the inventor of the 4004 eventually left Intel to found Zilog. HMMMM.

In 1989, some far-sighted folks purchased what is now Microchip from the semiconductor division of General Instruments. The PIC16C5X microcontrollers appeared, followed by the ground-breaking analog-to-digital-converter-laden PIC16C71. Tons of eight-bit Microchip PICs are currently available, ranging from tiny six-pin devices to 100-pin TQFP parts. We've witnessed the introduction of Microchip's 16-bit PIC24 and dsPIC devices and now we've seen Microchip evolve into the 32-bit PIC32MX family.

During all of this microprocessor and microcontroller innovation, have you ever considered that the eight bits that we all know as a byte may have been based on engineers holding up all of their non-thumb fingers? Don't think too hard on that last statement and don't let the 32-bit nature of the new PIC intimidate you. After all, we all know that the 16-bit concept came from counting those eight fingers and all of the non-big-toe toes in binary from right to left. And, it's common knowledge that a pair of software engineers thought up the 32-bit scheme.

Okay, enough of the binary jokes. Let's all take a deep breath and focus

on the very first page of the PIC32MX data sheet. It reads, *PIC32MX Family Data Sheet. 64/100-Pin General-Purpose, 32-Bit Flash Microcontrollers*. The words General-Purpose on the PIC32MX data sheet title page are very important. "General-Purpose" infers that the PIC32MX is not some specialized PIC that only a handful of us will ever use in a PIC project. If you step back and give it some thought, in an I/O sense, the new PIC32MX doesn't do anything more than the old PIC16C54 did. PIC microcontrollers are designed to be easily integrated into embedded applications that require basic and advanced elements of mixed data processing and I/O handling. The PIC32MX blinks an LED just like a PIC16C54 does. The difference is that the PIC32MX can not only blink that LED, at the same time it can blink that LED faster and in the process, perform tasks that the PIC16C54 had to relegate to external supporting devices. Another attribute that physically ties the PIC32MX to its PIC16C54 roots is that neither the PIC32MX nor the PIC16C54 are currently available in a ceramic quartz-windowed JW package.

Just in case you haven't had the opportunity to check out the PIC32MX data sheet, the PIC32MX's enhanced features include a maximum of 512K of program Flash and 32K of data memory. Recall that I mentioned that the old PIC16C54 maxed out with a 1 µs cycle time, which was supported by a 4 MHz clock. Folks on the Microchip PIC32MX forum are speaking in terms of MIPS as the PIC32MX can clock its MIPS32 M4K 32-bit RISC core at a maximum of 72 MHz. If you fell into the Microchip 16-bit bucket and have a PIC24 or dsPIC design that you would like to port to the PIC32MX, you may be in luck as the PIC32MX is pin compatible with most of the PIC24 and dsPIC microcontrollers. It's my opinion that Microchip also wants you to fall head first into the 32-bit bucket, as well. I base my prognostication on the $50 PIC32MX Starter Kit hardware, which I've shutterbugged for you in Photo 1.

THE PIC32MX STARTER KIT

The PIC32MX Starter Kit package is a sleeper. Coming in at $50, the PIC32MX Starter Kit includes the PIC32MX360F512L-based hardware you see in Photo 1, an A-to-MINI-B USB cable, and a CD-ROM stuffed with numerous PIC32MX code examples, documentation, and tutorials. The PIC32MX Starter Kit's PIC32MX comes preprogrammed with a Simon Says game that is based on the PIC32MX Starter Kit's onboard pushbutton switches and LEDs. Rather than frustrate myself with the memory game, I decided to load one of the other demo programs into the PIC32MX. The demo I chose to run uses the services of MPLAB 8.0 to prompt for command letters that correspond to LEDs on the PIC18F2620 Starter Kit board.

For instance, entering an "R" toggles the RED LED on the PIC32MX Starter Kit board. The letter "O" works on the ORANGE LED while "G" toggles the PIC32MX Starter Kit's GREEN LED. The demo program also allows the PIC32MX student to enter "E" to echo a string. Although the demo application sounds trivial, the PIC32MX programming concepts contained within the demo application are essential to grasp if you want to be successful with the PIC32MX.

As you would imagine, the PIC32MX is feature rich and thus, has a ton of supporting configuration registers. That's a good thing. However, having that kind of control requires complexity. The PIC32MX's ability to be configured down to the nits jives with my first rule of embedded computing: Nothing is free. To assist the new PIC32MX user in getting a 32-bit application up and running quickly, Microchip has graciously provided a set of API (Application Programming Interface) calls that take much of the finger work out of coding a PIC32MX project. The demo program I loaded into my PIC32MX Starter Kit board that looks for command letters also uses the API extensively. Fortunately, there are lots of examples that address each and every PIC32MX subsystem. For instance, here's a complete demo project that shows you how to systematically blink, all of the LEDs on the PIC32MX Starter Kit board:

```
int main(void)
{
int i;
        // setup LEDs
mPORTDClearBits(BIT_0);  //Turn off LED0 on startup
mPORTDSetPinsDigitalOut(BIT_0);   // Make LED0 as output
mPORTDClearBits(BIT_1);  // Turn off LED1 on startup
mPORTDSetPinsDigitalOut(BIT_1);   // Make LED1 as output
mPORTDClearBits(BIT_2);  // Turn off LED2 on startup
mPORTDSetPinsDigitalOut(BIT_2);   // Make LED2 as output

  while(1) { // do forever

    for(i=0; i<200000; i++);     // put a delay
    mPORTDToggleBits(BIT_0);     // turn ON LED0
    for(i=0; i<200000; i++);     // put a delay
    mPORTDToggleBits(BIT_1);     // turn ON LED1
    for(i=0; i<200000; i++);     // put a delay
    mPORTDToggleBits(BIT_2);     // turn ON LED2
  }
  return 0;
}
```

Judging from the code snippet I just presented to you, it's rather obvious which PORTD bits correspond to each of the PIC32MX Starter Kit's three LEDs. It's also pretty blatant as to what each of the PORTD API calls do. Repeat after me: *The PIC32MX is a general-purpose PIC*. All you need to get started coding that does not come in the PIC32MX Starter Kit box is the student edition of the Microchip C32 compiler, which you can get as a free download from the Microchip website.

The Microchip PIC32MX Starter Kit team knew that you and I would soon grow weary of only being able to push buttons and flash LEDs. So, they decided to place an ultra compact 120-pin Hirose connector on the opposite side of the PIC32MX Starter Kit board. The Hirose CL570-0103 header attached to the PIC32MX Starter Kit board you see in Photo 2 equates to a Hirose product number of FX10A-120P/12-SV1(**). If we want to go beyond blinking LEDS, we'll need to build up a compatible interface to the PIC32MX Starter Kit's Hirose header. After a bit of Hirose FX10A data sheet bending, I came up with a matching receptacle whose part number is CL570-0203-0-**, which translates to a Hirose product number of FX10A-120S/12-SV(71). The "**" values, or lack thereof, within the parentheses of the part number is a specifications number.

For those of you that want to explore the PIC32MX beyond blinking LEDs and sensing pushbuttons, I've taken Microchip's API approach to the hardware side. I've designed and realized a simple printed circuit board (PCB) that allows

■ PHOTO 1. This little board is meant to introduce you to the PIC32MX hardware and the new 32-bit C compiler that supports it.

■ PHOTO 2. The Hirose header in this shot looks like it would be a bear to mount without special SMT equipment. Not so. As it turned out, it's actually no different than mounting an 80-pin PIC as the pitch of the Hirose header (0.50 mm) matches that of a 16-bit, 80-pin PIC24FJxxxGA008.

you to simply plug in your PIC32MX Starter Kit board and gain direct access to all of the PIC32MX360F512L's pins.

I must admit that at first I was totally intimidated by the 120-pin header on the flip side of my PIC32MX Starter Kit board. So, for three days I gazed at the board's 120-pin header through my magnifier loop wondering if I could pull off mounting the matching 120-pin receptacle on a PCB of my own design. After sleeping on it one more time, I finally bit the bullet and ordered up 10 of the matching 120-pin receptacles from Digi-Key (H11234-ND). Why 10? I figured I'd ruin at least two of them in the design phase.

Upon receiving the receptacles, I studied them up close for the next couple of days. After determining that I could not easily bend or damage the receptacle's pins when handling the connector, I set out to build an ExpressPCB CAD footprint for the receptacle based on the PCB footprint CAD parameters contained within the Hirose FX10A data sheet. The result of my efforts can be seen in Screenshot 1. Once the Hirose 120-pin receptacle CAD work was done, the rest of the PIC32MX 32-bit expansion board came into fruition very easily. A shot of the final board in bare form is represented in Photo 3.

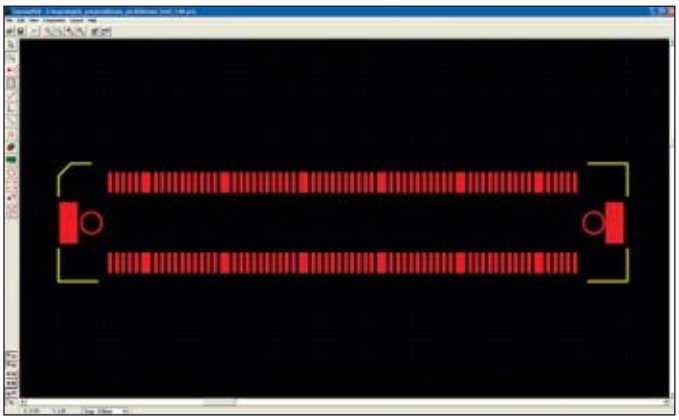
I have the fancy SMT equipment necessary to mount and solder the receptacle. However, you may not have that kind of equipment at your disposal and I feel that if you can't build the expansion board on your bench, it's of no use to you. So, I manually mounted and hand soldered the Hirose 120-pin receptacle as you can see in Photo 4. The 120-pin receptacle I used has a pair of guidepost alignment pins on its bottom side. I intentionally oversized the guidepost mounting holes by a few hundredths of a millimeter to allow for some play to guarantee precise manual mounting of the receptacle.

Once I got the 120-pin receptacle aligned, I spot soldered the ground plane lugs at each end of the receptacle to hold it firmly in place. The rest of the soldering process was no problem as I was able to concentrate on putting the solder and the soldering iron tip on my targeted receptacle pin. If you're in the smoke when it comes to soldering at this level, check out Aaron Dahlen's excellent SMT assembly article in the December '07 *Nuts & Volts*.

The PIC32MX 32-bit expansion board is very simple in design. The Hirose receptacle places ground plane connectors between every 10 pins of the receptacle with the exception of placing a ground plane connector pin at the sixth pin in from each end. I make a physical electrical connection between every receptacle ground pin and the top and bottom ground planes of the PIC32MX board. The combined use of the Hirose receptacle's grounding pins and the ground planes on the PCB reduces electrical noise. Note that there are no power or programming interfaces on the expansion board. That's because the PIC32MX Starter Kit board is powered by its on-board USB portal. The PIC18LF4550 that provides the USB interface for the starter kit board is also programmed to be used as the on-board debugger interface.

The power derived from the USB port (+5 VDC) is fed to a MCP1603-based synchronous buck converter circuit that converts the incoming USB power to +3.3 VDC, which is switched to the PIC32MX's Vdd pins via a FDN360P P-channel MOSFET. The MCP1603-based synchronous buck converter circuit's input can also be fed with an external +5 VDC source.

Both the PIC32MX's Vdd and external +5 VDC power connections exist on the 32-bit expansion board's 60-pin connectors. The starter kit PCB header connections are logically grouped with respect to their function (UART1, PMP



■ SCREENSHOT 1. There is absolutely nothing fancy here. I simply used the Hirose data sheet as a guide to producing the receptacle pads, their placements, and their clearances. ExpressPCB allowed me to custom-build the pads and holes you see in this shot to the Hirose data sheet specifications.

Address, PMP Data, etc.) on each side of the 120-pin header. As my 32-bit expansion board design simply brings out each side of the 120-pin header to a pair of 60 pin headers, the original logical intent of the Microchip PIC32MX hardware designers is kept intact. The expanded board is shown mounted via our 120-pin receptacle in Photo 5.

SUPER 82C55

Officially known as the 82C55 Programmable Peripheral Interface, the 82C55 is the CMOS derivative of the venerable Intel 8255A. Back in the days when the baseline 8048 and 8051 microcontrollers were just about all we microcontroller hobby types had to work with, the 8255A was the way to go as far as I/O expansion was concerned. In fact, when Microchip announced their new line of 17CXX PICs, I used a pair of 82C55s to augment the I/O of a PIC17C42 in a PIC16C5X emulator I designed.

The 82C55 is comprised of 24 I/O lines divided into three sets of eight. The host microcontroller attaches to the 82C55 by way of an eight-bit bidirectional bus and a handful of read/write/address lines. The way the 82C55 is utilized depends on how you configure the part using 82C55 control words. The programmer has three 82C55 modes to choose from, which include: Mode 0 – Basic Input/Output; Mode 1 – Strobed Input/Output; and Mode 2 – Bi-Directional Bus. The only real problem with the 82C55 is that it is slow and the average PIC would sit and spin for a long while waiting for the 82C55 to cough up its data. The PIC32MX has a built-in super fast 82C55-like subsystem called the PMP (Parallel Master Port). The PIC32MX's PMP can also be configured to operate in slave mode (PSP).

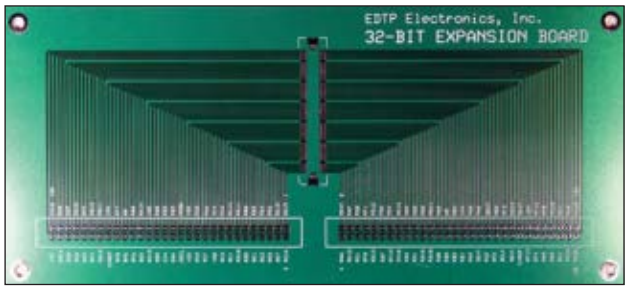
The PIC32MX's PMP provides the programmer/hardware designer with a maximum of 16 programmable address lines and can operate in eight-bit or 16-bit mode. The PMP built into the version of the PIC32MX found on the PIC32MX Starter Kit board also supports a 16-bit data bus. If your design will utilize the 64-pin variant of the PIC32MX, you'll only have an eight-bit PMP data bus to work with. Since I'm comparing the PIC32MX's PMP to the good old 82C55, I need to point out that the PMP also supports read/write/address control signals just like the 82C55, plus a few other things the 82C55 just can't do.

The 82C55 was designed to integrate external parallel peripherals into a microcontroller system's I/O with minimum parts and minimum coding overhead. The PIC32MX's PMP subsystem has the same mission. For instance, take a look at Figure 1. A standard LCD interfaces using four or eight data lines, a Register Select (RS) line, a Read/Write (R/W) line, and an Enable (E) line. As you can see, the PIC32MX's PMP supplies all of the necessary signal lines to drive a standard LCD module. What you don't see in Figure 1 is the flexibility of the PMP subsystem in this example.

To make this LCD driver work, the PMP must be programmed to act in eight-bit demultiplexed Master Mode. In addition, the LCD control lines are all active high levels, which is an attribute that is programmed into the PMP control line polarity mix. PMENB in this case is a write enable line. If the PIC32MX peripheral clock is too fast, the LCD module may miss the PMENB pulse on its E input. No worries! The PMP's PMENB pin can be throttled with programmable wait states. We have control of wait states before the pulse, wait states during the pulse, and wait states following the pulse. Can you say "covered?"

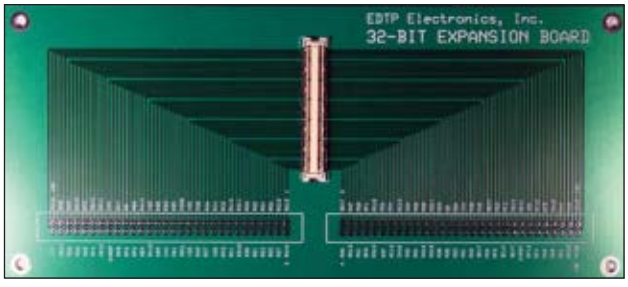
Figure 2 shows us how the PIC32MX's PMP subsystem handles simple eight-bit transfers from devices such as Flash, SRAM, or EPROM. Once again, the PMP is configured for eight-bit demultiplexed Master Mode. And, as with the PMENB output, the PMRD and PMWR signals can be configured with wait states and polarities to meet the access needs of the external eight-bit device. What you don't see here is that the PMP can be programmed to automatically increment or decrement the address value on every read/write cycle. You can't do that with an 82C55.

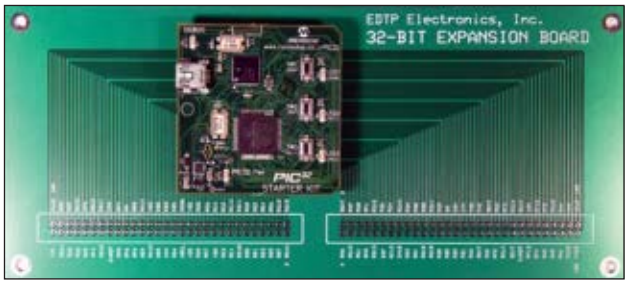
Before we move on, there's one more important attribute of the PMP I need to make you aware of. The PMP inputs are all five-volt tolerant. As long as the external device can pick out a logical high and logical low from the PIC32MX, no special logic level conversion circuitry is necessary. What



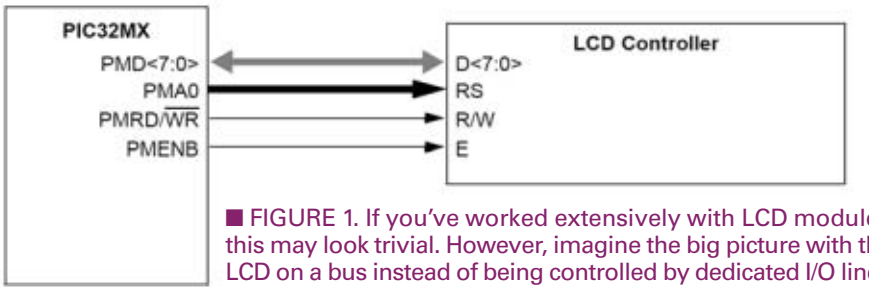
■ PHOTO 3. I went all out on this double-sided board. You can save some bucks and choose not to include the soldermask, but that will make the Hirose receptacle more difficult to solder onto the expansion board and you won't be able to identify each of the PIC32MX pins with silkscreen legends as I've done in this shot.

■ PHOTO 4. No sweat. After I aligned the 120-pin receptacle, I spot soldered the ground lugs at each end of the receptacle to hold the connector in place. With the receptacle properly aligned and firmly in place, the rest was simple to solder under the magnifier.

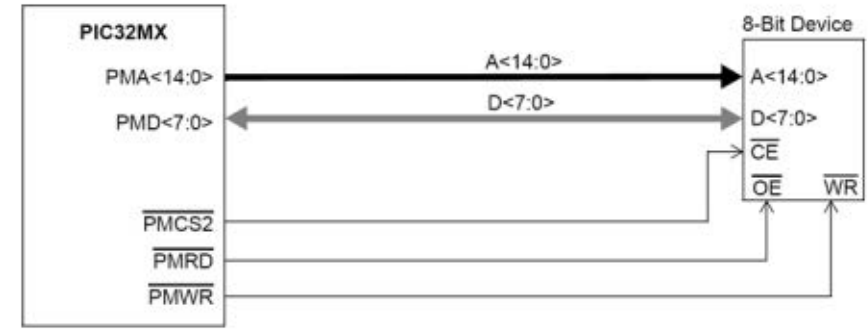




■ PHOTO 5. Here's the shot we've been working towards. We now have total access to all of the PIC32MX subsystems at the pair of 60-pin 0.1-inch headers.



■ FIGURE 1. If you've worked extensively with LCD modules, this may look trivial. However, imagine the big picture with this LCD on a bus instead of being controlled by dedicated I/O lines.



■ FIGURE 2. Note the inclusion of a PMP chip select line here (PMCS2). The PIC32MX PMP subsystem has two chip select lines available to the programmer.

you will find is that most TTL devices will recognize a logical high (2.4 volts and up) and logical low (2.0 volts and down) emanated by devices like the PIC32MX running at +3.3 VDC.

WE'RE NOT DONE YET

Now that we have a little bit of knowledge as to what the PIC32MX is all about and we have some hardware that exposes all of the PIC32MX's hardware features, we need to explore the 32-bit firmware that drives the PIC32MX360F512L. Your immediate task is to get your version of the PIC32MX Starter Kit 32-bit expansion board into the oven. To assist you, I've supplied the complete set of ExpressPCB files on the *Nuts & Volts* website (**www.nutsvolts.com**). And, if you're wondering where all of the schematics are, visit the Microchip website and click yourself into the PIC32MX documentation area. You'll find a complete set of PIC32MX Starter Kit schematics plus the schematic rendition of the 32-bit expansion board pinout. Have your hardware ready to go as we'll do some PIC32MX 32-bit firmware cooking in the next installment of the Design Cycle. **NV**

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- Useful for Currents to 50A, Voltages Down to 1.2V
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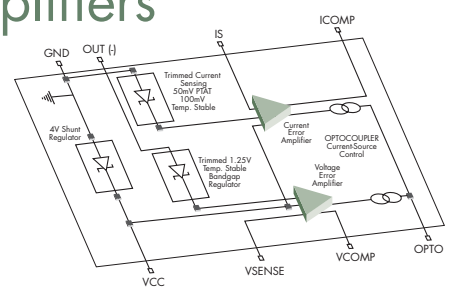

Ordering Information

Ordering PN (1)	Subgroup	Description	Temp. Range	Package	Packing Type	Packging Qty
IPS20C-D-G-LF	Feedback and Support	V/I FB and Cntrl, 50mV Vsen, Tcu Comp Ref	Commercial	8-Pin DIP	Tube	50
IPS20I-D-G-LF	Feedback and Support	V/I FB and Cntrl, 50mV Vsen, Tcu Comp Ref	Industrial	8-Pin DIP	Tube	50
IPS20C-SO-G-LF	Feedback and Support	V/I FB and Cntrl, 50mV Vsen, Tcu Comp Ref	Commercial	8-Pin SOIC	Tube	98
IPS20I-SO-G-LF	Feedback and Support	V/I FB and Cntrl, 50mV Vsen, Tcu Comp Ref	Industrial	8-Pin SOIC	Tube	98
IPS20C-SO-G-LF-TR	Feedback and Support	V/I FB and Cntrl, 50mV Vsen, Tcu Comp Ref	Commercial	8-Pin SOIC	13" T&R (2)	2500
IPS20I-SO-G-LF-TR	Feedback and Support	V/I FB and Cntrl, 50mV Vsen, Tcu Comp Ref	Industrial	8-Pin SOIC	13" T&R (2)	2500
IPS21C-D-G-LF	Feedback and Support	V/I FB and Cntrl, 100mV Vsen	Commercial	8-Pin DIP	Tube	50
IPS21I-D-G-LF	Feedback and Support	V/I FB and Cntrl, 100mV Vsen	Industrial	8-Pin DIP	Tube	50
IPS21C-SO-G-LF	Feedback and Support	V/I FB and Cntrl, 100mV Vsen	Commercial	8-Pin SOIC	Tube	98
IPS21I-SO-G-LF	Feedback and Support	V/I FB and Cntrl, 100mV Vsen	Industrial	8-Pin SOIC	Tube	98
IPS21C-SO-G-LF-TR	Feedback and Support	V/I FB and Cntrl, 100mV Vsen	Commercial	8-Pin SOIC	13" T&R (2)	2500
IPS21I-SO-G-LF-TR	Feedback and Support	V/I FB and Cntrl, 100mV Vsen	Industrial	8-Pin SOIC	13" T&R (2)	2500

(1) Only RoHS/Lead-Free Packaging is normally offered.
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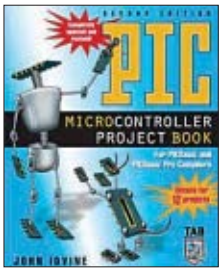
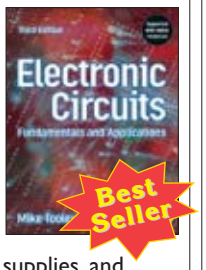
PIC Microcontroller Project Book
by John Iovine



The PIC microcontroller is enormously popular both in the US and abroad. The electronics hobbyist market has become more sophisticated. This new edition is fully updated and revised to include detailed directions on using both versions of the microcontroller, with no-nonsense recommendations on which is better served in different situations. **$29.95**

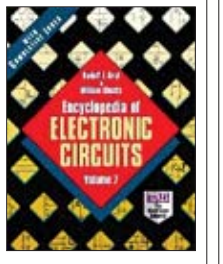
Electronic Circuits — Fundamentals & Applications: Third Edition
by Mike Tooley



In *Electronic Circuits*, Mike Tooley provides all the essential information required to get to grips with the fundamentals of electronics, detailing the underpinning knowledge necessary to appreciate the operation of a wide range of electronic circuits, including amplifiers, logic circuits, power supplies, and oscillators. The third edition now offers an even more extensive range of topics, with extended coverage of practical areas such as circuit construction and fault finding, and new topics including circuit simulation, electronic CAD, and a brand new chapter devoted to the PIC microcontroller. **$34.95**

Encyclopedia of Electronic Circuits, Volume 7
by Rudolf F. Graf / William Sheets

Publish Date: August 31, 1998



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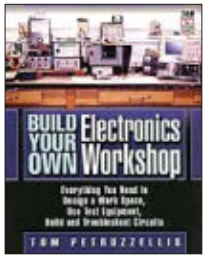

This value-packed resource provides everything needed to put together a fully functioning home electronics workshop! From finding space to stocking it with components to putting the shop into action — building, testing, and troubleshooting systems — popular electronics author Tom Petruzzellis' *Build Your Own Electronics Workshop* has it all! And the best part is, this book will save you money, big time! **$29.95***

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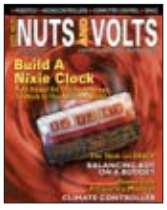

As seen in the October 2006 issue

Nixie tube clocks fuse the spirit, drama, and eerie beauty of cold war technology with modern inner works to create uncommon handcrafted timepieces. This clock / kit was shown at the October 2007 MAKER Faire in Austin, TX by *Nut & Volts Magazine* and was very well received as a novel way to show the Nixie tubes. Plus, it's a great kit for all levels of electronic experience.

For more information, please check out your October 2006 issue or go to our website @ www.nutsvolts.com

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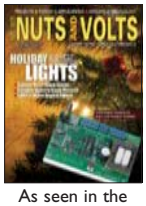

As seen in the November 2007 issue

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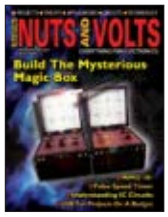

As seen in our April issue.

We received such great reviews on this magic box kit that we decided to offer it in our store.

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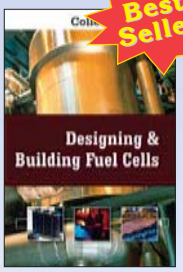
Best Seller



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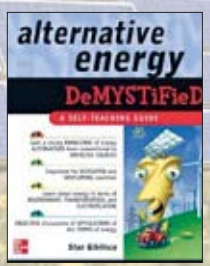
Alternative Energy Demystified
by Stan Gibilisco
Publish Date: October 23, 2006



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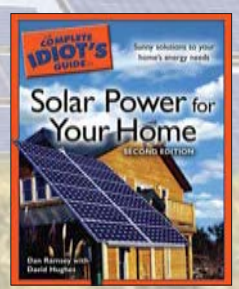
The Complete Idiot's Guide to Solar Power for Your Home
by Dan Ramsey / David Hughes
Publish Date: May 2007



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MUST HAVE

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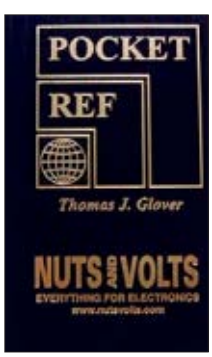
by Thomas J. Glover



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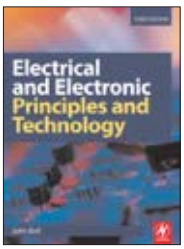
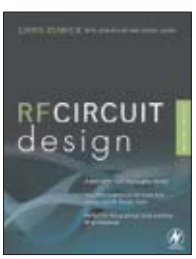
New To Our Store

Electrical and Electronic Principles and Technology 3rd Edition
by John Bird
Publish Date: October 1, 2007



In this book, John Bird introduces electrical principles and technology through examples rather than theory – enabling students to develop a sound understanding of the principles needed by technicians in fields such as electrical engineering, electronics, and telecommunications. **$39.95**

RF Circuit Design
by Christopher Bowick
Publish Date: October 26, 2007



RF circuit design is now more important than ever as we find ourselves in an increasingly wireless world. Radio is the backbone of today's wireless industry with protocols such as Bluetooth, Wi-Fi, WiMax, and ZigBee. Most, if not all, mobile devices have an RF component and this book tells the reader how to design and integrate that component in a very practical fashion. **$44.95**

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READER FEEDBACK

Continued from page 8

Response: First, thanks very much for your interest in my Bingo article. I really appreciate hearing from the readers. Second, I'll try and answer all your comments.

The "verify + 1" and "verify + 10" buttons were used to enable one to reach any number in the 75 numbers possible, as quickly as possible. For example, if one wanted to verify the number 72, you only need to push the "Verify + 10" button six times to get to the number "71," then one time on the "Verify + 1" and you are at 72 rather than having to hold down the "Verify + 1" button long enough to reach 72. The verify portion of the program runs independently from the number choosing portion, so both can actually be done at the same time. After all 75 numbers have been chosen, no more choices will appear on the output.

I didn't see any reason to use a random number generator, since timer 0 runs constantly, and the time of pushing the "choose a number" button is completely random depending on the person calling the numbers. You are correct, it would have been nice to have a sounder and a flashing light but, of course, the device I built does not know when someone has called Bingo. I didn't automate that much of it, trying to keep the project simple and inexpensive. Again, thanks for your comments and questions.

— Chuck Irwin

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All questions *AND* answers are submitted by *Nuts & Volts* readers and are intended to promote the exchange of ideas and provide assistance for solving problems of a technical nature. Questions are subject to editing and will be published on a space available basis if deemed suitable by the publisher. Answers are submitted by readers and NO GUARANTEES WHATSOEVER are made by the publisher. The implementation of any answer printed in this column may require varying degrees of technical experience and should only be attempted by qualified individuals. Always use common sense and good judgement!

All questions and answers should be sent by email to forum@nutsvolts.com All *diagrams should be computer generated and sent with your submission as an attachment.*

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❷ Electronic Theory
❸ Problem Solving
❹ Other Similar Topics

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■ Comments regarding answers printed in this column may be printed in the Reader Feedback section if space allows.

>>> QUESTIONS

I'm learning electronics on a self study basis. My main book has a brief section on impedance matching. The key idea is that power transference will be at a maximum when the source impedance is equal to the load impedance. It doesn't do a very good job demonstrating the math. I need a more detailed explanation.

#2081 **Mark Jungmeyer**
via email

I am converting a 1981 DeLorean into an electric vehicle and I need advice on building a battery charger for my series string of 13, 12 volt Deka 9A31 AGM (sealed absorbed glass mat) batteries which are 100 Ah each. The manufacturer recommends a three stage charge cycle:

First, start with a constant current of 30 amps until the voltage of each battery reaches 14.4-14.6 volts (187.2-189.8 volts for the string).

Second, charge at a constant voltage of 14.4-14.6 volts (187.2-189.8 volts for the string) until "the current acceptance drops by less then 0.10 amperes over a one hour period;" max time 12 hours.

Third, maintain a constant terminal voltage of 13.5 volts (175.5 volts for the string).

It would be best to have an option to operate off 110 volts when 220 volts is not available and to optionally limit the supply current so as not to overload a low capacity circuit breaker when charging away from home.

Ideally, it would be better to charge each battery separately so they are properly balanced, but using 13 chargers seem a bit too bulky. Any ideas?

#2082 **Dave Delman**
Jericho, NY

I'm trying to interface a thermal IBM PC Compact Printer (Model 5181001) to a micro and need the Tech manual, or information describing the timing, commands, and pinouts of the printer. I've searched the Web, but can't locate any info other than it was used with IBM PC Jr. Plenty of these printers are for sale, just no documentation that I can find.

Does this printer have the same interface as another printer that I might be able to locate?

#2083 **Bruce**
via email

I need a cheap — but reliable — remote liquid level sensor setup for my home heating fuel oil tank.

#2084 **Will**
via email

>>> ANSWERS

[#11074 - November 2007]

Is there a unit or circuit to

convert HDMI to IEEE?

There is not a circuit or device to convert HDMI to IEEE because IEEE stands for Institute of Electrical and Electronics Engineers, an international nonprofit organization (**www.ieee./org).** This is not a protocol/specification such as HDMI (High-Definition Multimedia Interface). You must add a series of numbers after "IEEE" to refer to a particular standard such as IEEE 488, IEEE 802.11, IEEE 1394, and so forth.

HDMI is a licensed interface which uses uncompressed and encrypted data to interface DRM (Digital Rights Management) audio-video devices/sources including computers and satellite dish systems to compatible televisions, audio devices, etc. Due to the DRM aspect, it is not likely possible or legal to convert HDMI to some other form of signal (digital or analog) to bypass the copyright protection.

Erik
Escondido, CA

[#12071 - December 2007]

I have noticed that many of the leads on capacitors and LEDs are magnetic, as are the bodies of carbon-film resistors (but not the leads). Why is that? Why not copper wire? Why is there iron in a carbon film resistor?

#1 Many of the leads are magnetic because they are made of steel. This steel is then "tinned" with either solder, pure tin, silver, or gold. One would suspect the reason for using a "base metal" such as steel would be material cost, but actually it is so there is the correct tensile strength to allow for bending prior to insertion in a circuit board. The leads are tinned to make soldering more efficient. Solder adheres very well to gold, silver, and tin.

Many mil-spec semis have gold tinned leads. Some have silver tinning. If these have been in storage a while, they will oxidize and turn black (just like silverware does) and solder will no longer stick. To use these parts, the leads must be cleaned, either manually using an "Eraser" brush, or I have found that Tarn-X will remove the oxidation (the part must be water washed and dried afterwards).

Solder tinning has just about gone away due to RoHS (the Reduction of Hazardous Substances initiatives in Europe and California). Everyone is afraid of lead these days, and traditional solders are an alloy of tin and lead. Most parts are now tinned with pure tin (now you know where the term "tinning" originated!).

Pure tin is showing some longetivity problems in that it tends to whisker over time and on close pitch parts, can cause an early device failure. Parts tinned with solder do not seem to exhibit this problem. Although the agencies pushing elimination of lead have exempted components used in military and communications applications, most manufacturers are only making the lead free variety now, as it is cost-prohibitive to run two parallel production processes for the same base part.

For more information on RoHS, visit **www.rohsusa.com**.

Phil Shewmaker
KG4ERX

#2 Many years ago, an iron alloy was developed to have the same coefficient of expansion as glass. This made it possible to bring wire leads out of glass sealed units without leakage. This wire is cheap and readily available, probably less expensive than copper. It is also magnetic. Carbon film resistors are fabricated on a ceramic core. The end cap that holds the core is steel and is magnetic. The end cap makes the connection between the carbon film and the copper wire.

Russell Kincaid
Milford, NH

#3 Copper is not used because of the cost and the added heat conduction is not needed. In most applications in PCBs, the leads are so short that it wouldn't make any difference in the heat dissipation capability of the device.

Phillip Milks

#4 On capacitors, LEDs, and many transistors, the leads are also the physical support. For example, a TO-5 cased transistor running at its power limit might be mounted high off the circuit board and have a "flag" style heatsink. Copper leads wouldn't be

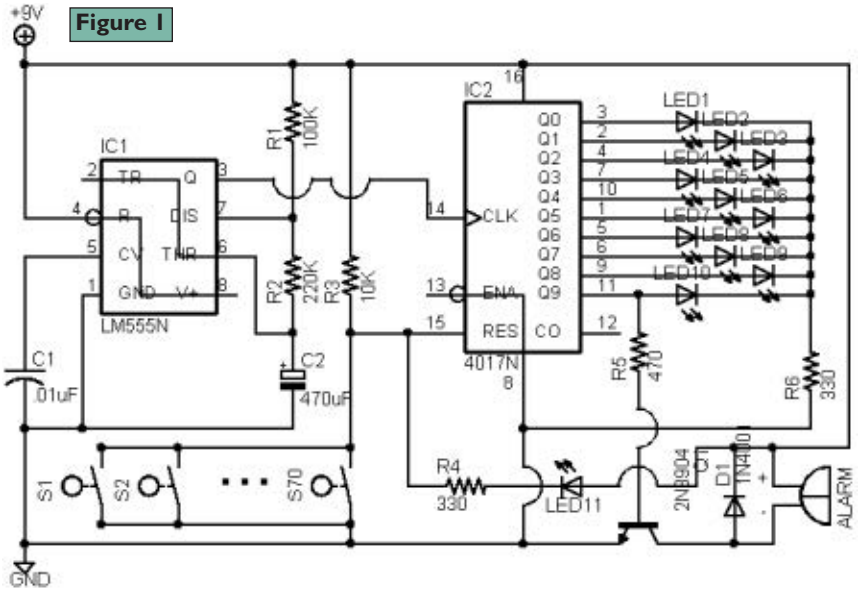
Correction

There is an error in the schematic diagram accompanying my answer in the November issue to question #08074.

Figure 1 is the correct schematic. The text of my answer remains the same.

Ed Schick
Harrison, NY

Figure 1



stiff enough. The steel leads are sometimes plated with gold to prevent corrosion and improve conduction.

For the carbon film resistors, I suspect the iron — or soft steel — is an inexpensive but sturdy core that can be coated with ceramic or glass, then the carbon.

Dale Yarker
via email

[#11075 - November 2007]

Years ago, I built several "Nothing Boxes" that fascinated friends. They were boxes with six to 10 flashing NE-2 lamps. They needed over 120 volts, usually from three surplus 45 volt batteries which were hard to find.

Can anyone provide a simple but efficient power supply that could be used with 6 to 12V and provide the 120 to 140 volts needed by the NE-2 oscillators? I would probably use C or D cells so that the boxes would run for several months on one set of batteries.

#1 Jameco Electronics sells a 12V power supply for fluorescent lamps that may work for you. Its output is 180V or so; Part #239636. It will probably work on less than 12V, as well.

Bob Lindstrom
Broomfield, CO

#2 Years ago, I assembled a "goofy night light" P-Box kit from RadioShack. That kit had five neon bulbs that could be configured to flash in sequence or randomly. The kit was made to run off of six volts DC and advertised that if you used four D cells or a lantern battery, it would run for months.

Figure 2 is a simple power supply schematic gleaned from part of that kit. The power supply is a simple oscillator that runs on 6 VDC with a single PNP transistor. The oscillator output is stepped up to around 100-150 VDC with the transformer. Almost all components are off the shelf. The transformer is an audio output transformer, like those used in many older audio amplifiers. You can probably find one in a discarded radio from the 1970s.

E. Kirk Ellis, KI4RK
Pikeville, NC

#3 How about a free power supply and as a bonus, a free battery to run it? Go to a photo developing store and ask for a used disposable camera. When you take it apart, look for these:

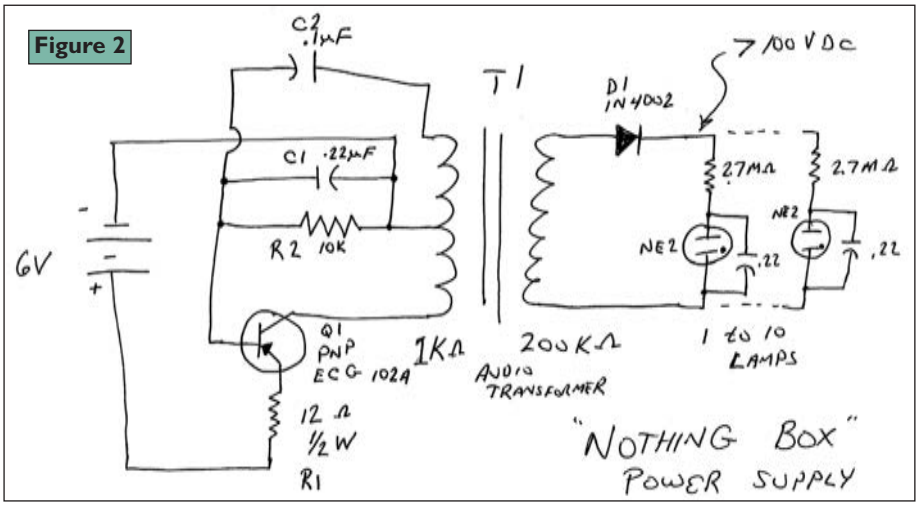
1) Contacts that when closed, energize the flash option.

2) The large (slightly smaller than an AA cell) high-voltage storage capacitor.

Close the contacts **(1)** to begin charging the capacitor. After a few seconds, the small neon lamp (similar to an NE-2) will flash. With a meter, you can measure the capacitor voltage which will be around 300 VDC. This will run your "Nothing Box," although you may want to change the resistor values if the flash rate is too fast.

If you want to see the camera strobe lamp flash, hold the contacts **(1)** closed and simultaneously close the contacts that are connected to the shutter release mechanism.

Mr Google has links to dozens of sites related to hacking these cameras.



Helpful hint: Do NOT wet your finger and touch the capacitor contacts when it is charged!

Sid Knox, W7QJQ
Oklahoma

#4 The answer can be found with the MAX1932. The standard circuit for this part makes 90V and operates from 3 to 5V input, so three AA cells is all that is needed. This circuit also has a nice current limit so it will make it safer than a garden variety boost.

The datasheet and circuit are here: **http://datasheets.maxim-ic.com/en/ds/MAX1932.pdf**

Len Sherman
(works for Maxim)

#5 I built one of those many years ago and used 110 volts right out of the wall. Many more years later, I built another one using a bunch of nine volt batteries in series. That was safe but did not last long. I later used a DC-to-DC converter fed by five AA cells. It worked well and would probably last for months with D cells. The converter I used was a PICO 5B48S. I used small neon bulbs without sockets and 2.2 meg resistors. Put the whole thing in a clear plastic box. Piece of cake. Good luck and keep having fun!

Tom Grabowski
Baltimore, MD

#6 Buy 12 nine volt batteries and snap them together in series for 108 volts at the two remaining terminals. The neons may light at as low as 90 volts. Add more batteries to the series string if you think you need more than 108 volts.

D. Crunkilton

[#12072 - December 2007]

I subscribe to cable phone with a company that provides a bundle of high-speed Internet access, television, and phone service. A cable problem can cause any one or all three to crash. My primary concern is about the phone. When it goes out, you won't know it until you try to use it and get no dial tone, or if someone tells you later that they could not reach you. This has caused me to miss important calls and deliveries. Is there a circuit I could build

to monitor the cable phone line and alert me (e.g., beep, buzz, blinking light, etc.) when it goes down? My provider hasn't a clue, and only apologizes for the inconvenience over and over again.

As one who monitors the operation of thousands of "cable phones" daily, I can tell you that there are many reasons why your phone may lose dial-tone or inbound calls do not ring your phone or go to voicemail even though your phone is idle. The PacketCable technology used to deliver such service has come a long way and cable phones are certainly a viable option today, but many complex technologies have to work correctly all at the same time in order for your phone to function properly.

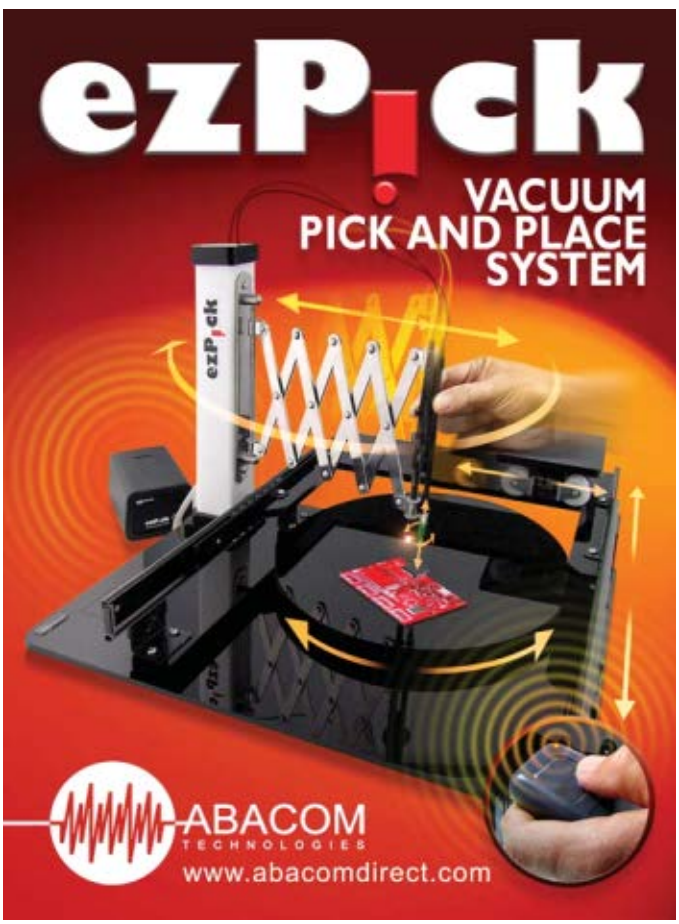
In a Plain Old Telephone Service (POTS) network, the central office only has to apply DC or simple AC voltage waveforms to your phone to provide dial-tone or to make it ring. It is hard to beat the reliability of such a simple network.

Signals on your cable network are carried to and from your Enhanced Media Terminal Adapter (EMTA) using complex modulation techniques over RF signals on fiber and coaxial networks. Even in the best of cable networks, these signals can be impaired by noise generated in your neighbor's home, by a local radio transmitter, or created within the cable system itself by faulty connectors. The signal level can be too high or too low because of faulty or incorrectly adjusted lasers and amplifiers or because of faulty wiring in your home. If the telephone switch in the cable head-end tries several times to signal your EMTA of an inbound call via the Media Gateway Control Protocol (MGCP) and signaling packets are lost because of such impairments, the call will fail. Often, the condition is intermittent and even the cable operator will have a difficult time detecting these.

There are conditions that may cause you to lose the RF signal altogether when a cable is cut or during a maintenance on the network. If you are really motivated to detect and put an alarm on this condition, I suggest (despite my better judgement) that you pull the cable off of the back of your EMTA and notice what activity occurs on the front panel LEDs. Then, consider a circuit that uses photo detectors taped in front of one or more LEDs and connected to a circuit that detects LED activity that occurs during the "outage" and sounds an alarm. Or, take a look at what happens to the voltage on the telephone side of the EMTA. Some EMTAs will drop the telephone line voltage when they lose RF. I learned this the hard way when a customer's burglar alarm sounded each time the EMTA lost RF signal. You could build a circuit to detect this and alert you.

If you do not already subscribe to your MSO's voicemail service, I recommend that you do so. In cases where the inbound call fails because of a problem between the phone switch and your EMTA, it should be directed to voicemail.

John Montalbano
Middletown, NJ



IN THE SPOTLIGHT

An Interview with Ray Bellantoni
Vice President of Marketing, Jameco Electronics

by Marvin Mallon

The spotlight this month is on Jameco Electronics — a northern California firm located about 20 miles south of San Francisco. It is a privately owned company housed in a 50,000 square foot facility. They are a leading online and catalog distributor of electronic components and are ranked 45th among the top electronic distributors in the nation. Jameco's first promotion was a small ad in *Radio Electronics*. The significant response to that led them to create a two-page, black-and-white catalog. They now distribute a full-color, 212-page catalog to millions of customers each year.

The company's broad product line includes semiconductors, passives, interconnects, electromechanical devices, power sources, and specialty products. They carry more than 100,000 products from over 300 manufacturers. A partial list of the most popular organizations they represent includes Fairchild, Intel, TI, Micron, Toshiba, Amphenol, and Panasonic. Additionally, in 2004, they introduced their own branded products, the Jameco ValuePro™ line of PEMCO products; the Jameco ReliaPro™ line of power supplies and motors; and the Jameco BenchPro™ line of accurate, professional-grade workbench tools.

Dennis Farrey, who remains as Chairman of the Board, founded the company in 1974. Bob Croshaw is the president and CEO, and Ray Bellantoni serves as Vice-President of Marketing. When interviewed recently for this column, Ray responded to our questions in this manner:

Marvin: Can you give us some idea of who Jameco's principal customers are?
Ray: Jameco's largest and fastest growing segment, the corporate customer, is driving product strategy and growth. That product line has increased over a magnitude since 2003 by responding to the needs of this customer base. Jameco also has a loyal group of hobbyist customers. In March 2005, the company purchased the first and most recognized robotics website, RobotStore.com. This strategic acquisition adds to the expanding product portfolio offered to hobbyists.

M: What is the principal focus of Jameco's business?
R: Jameco focuses on the most commonly needed electronic components. General areas include integrated circuits, discrete and passive components, connectors, power components, prototyping supplies, tools, test equipment, and computer products. Jameco consistently adds new products to meet customer demands. The product line has grown vastly in the past two years, and the company is aggressively adding more commonly used products. Jameco backs these, and all its products, with its low-price guarantee. A highly competent in-house technical support staff supports our products.

M: Can you summarize Jameco's present policies and future endeavors?
R: With the Jameco catalog, you don't need to search through thousands of pages to find the products you want. We don't flood our catalog with every product to make our catalog thicker. We carefully select the industry's most frequently used product lines so our customers can find what they need quickly and easily. The 100s of thousands of additional products we carry are listed on our website with detailed descriptions, data sheets, and cross-reference capabilities. In 2008, we will continue to push ourselves to bring our customers the best selection of the products they need, all at the best prices and the best service levels available.

At Jameco, we are committed not only to meeting, but exceeding, industry standards. In order to meet our customer's expectations, we rigorously test our products and back them with our 30-day money-back guarantee. Our convenient ordering options include online, 24/7 toll-free phone/fax, email, will-call, and postal mail. Nine payment methods allow for maximum flexibility. Orders placed by 6 pm EST are shipped the same day. Other services include scheduled shipments, kitting, volume discounts, and special sourcing for hard-to-find products.

In order to exceed our customer's expectations, we offer the lowest prices on all major brands, as well as even greater values on our in-house brands. Our customer-friendly catalog offers the opportunity for side-by-side comparison shopping — an exclusive feature in our industry. We are constantly expanding our product line in direct response to customer needs. In the last two years alone, our product line has grown vastly by adding the most commonly needed items. More than 99% of our catalog items are in stock, ready to ship, representing significantly greater availability than similar distributors. **NV**

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40W Series Available in 5,12,15,24,48V	$22.50	$18.90	$15.89
60W Series Available in 5,12,15,24,48V	$26.88	$21.92	$18.25
100W Series Available in 3.3,5,7.5,12,15,24,48V	$32.80	$26.49	$22.50
150W Series Available in 5,7.5,9,12,24,28,36V	$40.75	$33.70	$27.90

Stepper Motors

Part #:	Motor Frame Size:	Holding Torque:	Price:
42BYGH404	NEMA 17	3.4kg.cm/47oz.in	$17.95
57BYGH207	NEMA 23	8kg.cm/111oz.in	$24.95
57BYGH303	NEMA 23	15kg.cm/208oz.in	$29.95
57BYGH405	NEMA 23	20kg.cm/277oz.in	$34.95
85BYGH350B-03	NEMA 34	48kg.in/665oz.in	$79.95
85BYGH350C-03	NEMA 34	63kg.cm/874oz.in	$119.95

Stepper Motor Controllers: 2 Phase Microstepping Stepper Motor Driver (Bi-polar & Unipolar Motors)

Part #:	Dimensions:	MicroStep:	Price:
XCW220	100mm x 61mm x 19mm	1(200), 1/2(400), 1/4(800), 1/8(1600)	$39.95
CW220	99mm x 65mm x 30mm	1/2(400), 1/8(1600)	$49.95
CW230	115mm x 72mm x 32mm	1(200), 1/2(400), 1/4(800), 1/8(1600), 1/16(3200), 1/32(6400), 1/64(12800)	$59.95
CW250	140mm x 94mm x 45mm	1(200), 1/2(400), 1/8(1600)	$69.95
CW860	147mm x 97mm x 30mm	1(200), 1/2(400), 1/4(800), 1/8(1600), 1/16(3200), 1/32(6400), 1/64(12800), 128(25600), 1/5(1000), 1/10(2000), 1/25(5000), 1/50(10000), 1/125(25000), 1/250(50000)	$119.95

Sirocco SMD Rework Unit

The CSI-6028 is a small yet powerful rework system. The Sirocco style fan induces seamless airflow thru the heating element providing convection style heating, and this non-pressurized air stream works perfectly for reworking highly sensitive IC packages such as BGA, QSP, SOP and plastic based SMD devices.

Item # CSI-6028 **SALE! $79.00**

Details at Web Site

> Soldering & Rework > Hot Air Rework

Digital Storage Oscilloscope Module

Convert any PC with USB interface to a high performance Digital Storage Oscilloscope. This is a sophisticated PC basedscope adaptor providing performance compatible to mid/high level stand alone products costing much more! Comes with two probes.

Price Breakthrough!

Details & Software Download at Web Site

> Test Equipment > Oscilloscopes

PC based Digital Storage Oscilloscope, 200MHz 5GS/s equiv. sampling USB interface

Item# 200DSO Only $819.00

Soldering Station w/Iron & SMD Hot Tweezers

- Electrostatic discharge safe design with grounding measure
- Tweezers directly applies heat to components being repaired while avoiding nearby components
- Suitable for crowded circuit boards
- 24V output voltage to ensure safety of user and protect soldered components on board

Details at Web Site

Item# CSI-950+ $59.00

> Soldering & Rework > Soldering Stations

mCU Controlled True RMS High Accuracy DMM

The CSI2205D Micro Control Unit auto-ranging DMM is **UL Listed** and designed for measuring resistance, capacitance, DC & True RMS AC voltage, DC & True RMS AC current, frequency, duty cycle and temperature, along with the ability to test diodes, transistors and continuity. A special feature included is the Auto Test Lead Input Indication Technology. This will ensure that whenever you switch functions on the DMM, the proper positive port LED will light indicating where to plug the red test lead into so that no mistakes can be made by the user. It even goes so far as to give a warning tone if you do plug the lead into the incorrect jack! A very helpful feature for the novice and even for the experienced user who is using the meter in less then ideal lighting conditions. Overall, we find this to be a meter that compares very favorably with much higher priced competitors on the market today!

HOT Item!

Details at Web Site

> Test Equipment > Digital Multimeters

Item # CSI2205D **Only $59.00**

3-1/2 Digit LCD Panel Meter (enhanced version)

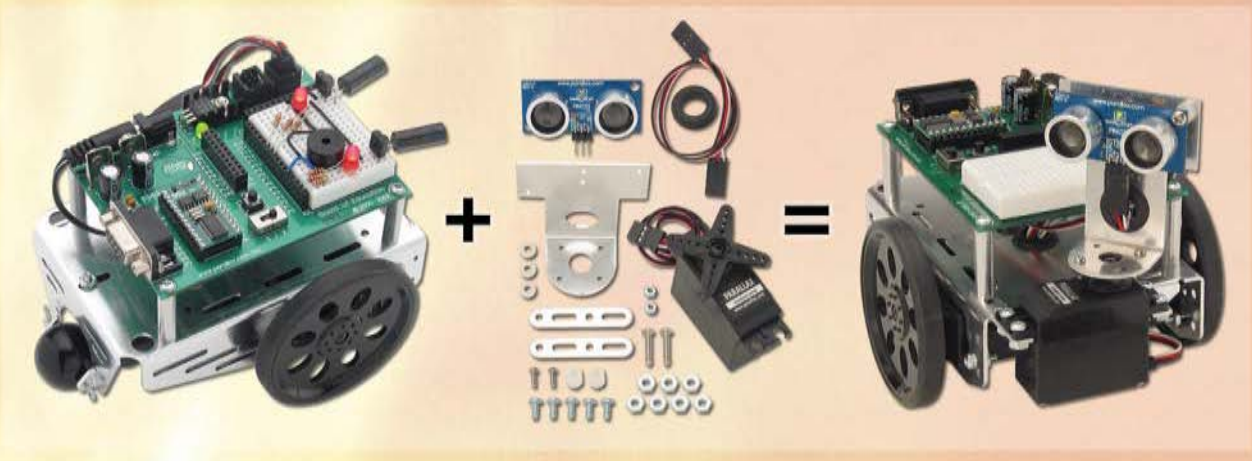
The PM-128E is an enhanced version of our best selling PM-128A. The E version can be set to work with either a 5VDC or 9VDC power source, will perform with either a common ground or an isoalted ground, and is supplied with easy to use jumper points so the end user can easily set the measurement range required.

Details at Web Site

> Panel Meters > Digital LCD Display

$12.25 Quantity Price Breaks at website!

Item# PM-128E



Give your robot a new perspective!

With the Parallax PING)))™ sensor and Mounting Bracket, your robot can do a quick 180° environmental scan to identify the location and distance of the objects in its path. The PING))) sensor measures distances from 2 centimeters to 3 meters by emitting an ultrasonic pulse, measuring the echo return time, then outputting a variable-width pulse corresponding to distance-to-target. The optional Mounting Bracket Kit includes a standard servo, extension cable, and complete hardware for mounting the PING))) sensor on the front of a Boe-Bot® robot.

Download sample BASIC Stamp® code, demo video demos and other resources from the 28015 and 570-28015 product pages at www.parallax.com.

- **PING))) Ultrasonic Sensor** (#28015; $29.95)
- **PING))) Mounting Bracket Kit** (#570-28015; $19.95)
- **Boe-Bot Robot (Serial/USB)** (#28132; $159.95)

Order online at www.parallax.com or call our Sales Department toll-free 888-512-1024 (Monday-Friday, 7 a.m. - 5 p.m., PST).

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